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AIRCRAFT CABIN OZONE MEASUREMENTS ON B747-100 AND B747-SP AIRCRAFT
Correlations With Atmospheric Ozone and Ozone Encounter Statistics

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SUMMARY

Simultaneous measurements of atmospheric (outside) ozone and ozone levels in the cabin of the B747-100 and B747 SP airliners were made in order to evaluate the aircraft cabin ozone contamination problem. This was accomplished by an extension of the NASA Global Atmospheric Sampling Program (GASP) to measure ozone at one point in the cabin.

The average concentration of ozone in the cabin of the B747-100 was found to be 39 percent of the outside concentration. However, ozone in the cabin of the B747 SP averaged 82 percent of the atmospheric value. Corrective actions were taken to lower the level of ozone in the cabin of this particular aircraft. Changes in the cabin air circulation system reduced the level to 58 percent. Application of high temperature fifteenth stage compressor bleed or installation of charcoal filters in the inlet cabin air ducting significantly lowered the ozone level to about 19 percent and 5 percent respectively.

Atmospheric ozone encounter statistics for GASP equipped B747 airliners are presented to establish the susceptibility of the flights of these aircraft to high levels of cabin ozone. Ozone encounters from March 1975 through December 1976 exhibited a maximum frequency in the spring for the Northern Hemisphere. Encounter frequencies for the three B747-100 airliners equipped with GASP were comparable even though the route structure for the aircraft was different. The B747 SP, however, encountered higher ozone levels than did the B747-100's.

Ozone measurements in the cabin presented here are limited to a few selected flights. A more extensive data base will be obtained as this data acquisition program continues.

INTRODUCTION

During the winter of 1976-77, the airlines received a number of reports from passengers and crew members describing physical discomfort that could have been caused by several factors. Many reports

came initially from the long distance nonstops such as between New York and Tokyo on which the new B-747 SP (Special Performance) aircraft is used by Pan Am. A B-747 SP operated by Pan Am is equipped with a NASA-GASP system designed to measure, among other air constituents, atmospheric ozone. Later during the winter of 1977 similar reports of discomfort were received by other airlines using B-747's and other types of aircraft on domestic flights. One of these was a B-747-100 operated by United Airlines and also equipped with a GASP system. Although ozone in the cabin was suspected as a cause of physical discomfort, it was not positively identified until high ozone concentrations measured outside a GASP equipped aircraft correlated with the reports of these adverse physical effects.

In considering ways of better defining the problems and effectiveness of corrective actions, an extension of the GASP equipment capability was made on these two GASP equipped B-747 aircraft. This involved measurements of ozone at one point in the cabin made simultaneously with outside (ambient) measurements. The GASP system had capability to make both measurements with existing equipment. Because of the extreme and rapid variability of ozone in the atmosphere, simultaneous measurements were considered necessary. These measurements were started in April 1977 and are continuing.

Ozone concentration measurements, both atmospheric and in-cabin, are planned to continue with GASP equipped aircraft during the coming peak ozone season. A major emphasis will be on the evaluation of the effectiveness and characteristics of present and proposed corrective actions. In addition, ozone concentrations in executive jet aircraft (Lear Jet) will be investigated using existing GASP equipment and similar procedures as used on the 747's (simultaneous inside and outside measurements). This work will be done at NASA Lewis during the winter 1977-78.

This report presents ozone measurements by the GASP system in the cabin of two B-747 aircraft (747-100 and 747 SP), correlations of these measurements with atmospheric (outside) ozone, statistics of

atmospheric ozone concentrations encountered by four B-747 aircraft during routine airline operations for 1976, and a brief description of the GASP ozone measurement system.

OZONE MEASUREMENT SYSTEM

Instrument Type

Ozone is measured with an ultraviolet absorption photometer with a range of 3 ppb to 20 ppm. Figure 1 is a block diagram of this instrument. The instrument has an ultraviolet source, an absorption tube through which the sample flows, an ultraviolet detector, and an electronic signal conditioner. This instrument works on the principle that ozone in the air sample absorbs some of the ultraviolet light passing through the sample. Thus, it is necessary to accurately measure small changes in the ultraviolet light coming out of the absorption tube. The instrument does this by alternating between measurements of ozone-free air and the sample. The ozone-free air is obtained by routing the sample through the ozone scrubber during half of a 20-second cycle. Sample measurements are taken during the last half of the cycle. Thus, the instrument updates every 20 seconds.

Modifications of the commercial version of this instrument (made by the Dasibi Co.) were required for airborne use. These included aircraft 400 Hz, 115 volt power supply, conforming to RTCA specifications for airborne electronic/electrical equipment and instruments (circuit improvements to meet EMI specifications required), and packaging to airline standards (Air Transport Equipment Racking and Cases, ARINC Characteristic Number 404).

In-Flight Checks

Certain in-flight tests are made to ensure the integrity of the measurements. These tests include an overall zero measurement and a measurement of two electronic signals that indicate the condition of the ultraviolet source and the presence of excessive contamination on

the absorption tube windows. For the zero measurement the sample is routed through a charcoal filter upstream of the instrument. The span setting of the electronics is also made. These checks are made in succession once every hour between data points.

Calibration

The accuracy of the ozone measurements depends on a number of factors. The calibration standard now used for GASP is the long path photometer at the Jet Propulsion Laboratory. A commercial Dasibi instrument is periodically calibrated against this standard and then held at NASA - Lewis as a secondary standard to which the airborne units are periodically calibrated. The airborne units calibrate 9% higher than the JPL standard. The resulting estimated uncertainty of the flight units is $\pm$ 3%. The airborne instruments have a long term repeatability within $\pm$ 2%.

The atmospheric air sample is pressurized and controlled to 1 atm. with a diaphragm-type pump to provide adequate sensitivity at upper altitudes. Some ozone destruction occurs in the pump and Teflon sample lines. This correction is 8 $\pm$ 5 percent of the indicated ozone concentration. System checks on this correction are performed periodically on the aircraft under conditions simulating operations in flight.

The cabin air sample is not separately pressurized. Differential pressure between the cabin and outside static is used to provide flow through the instrument that measures cabin ozone (same type instrument). A correction is applied to the ozone measurement for cabin air density, since the instrument is calibrated at 1 atm. A measure of cabin pressure is made by the GASP system for each ozone measurement.

Data Acquisition System

Ozone data (atmospheric and in-cabin) are taken with the existing GASP data acquisition and control system. All major components of this system are airborne units used by many airlines in normal flight data recording systems. The preprogrammed processor for automatic system control is a modified Data Management Unit. This unit also provides

certain data acquisition functions. Additional data acquisition is handled by a standard Flight Data Acquisition Unit. All data are recorded on a digital cassette recorder which is the same type Digital Aids Recorder (DAR) used by airlines for flight data recording. The GASP system is autonomous having dedicated units for all data acquisition and system control.

Instruments are turned on during aircraft preflight. The computer or processor takes over control just prior to takeoff. A standby condition is held until a signal is received by the processor from the altimeter to set up the system for sampling. A basic 60-minute sampling cycle is constructed by alternating 5-minute air sampling and 5-minute calibration modes. Thus, there are six sample readings and six different calibrations taken each cycle. All data are recorded during a 16-second period at the end of each 5-minute air sampling and calibration modes. The ozone instrument requires only four calibrations during each 1 hour cycle. Thus, ozone measurements are taken every 10 minutes during the first 40 minutes of the cycle and every 5 minutes during the remaining 20 minutes. The system can be modified to record data continuously with or without calibration periods. Before landing the system is returned to a standby condition.

RESULTS AND DISCUSSION

Aircraft Cabin Ozone Measurements and Correlations With Atmospheric Ozone

Simultaneous measurements of cabin and atmospheric ozone were obtained from the B-747 and B-747 SP aircraft at irregular intervals between March and October 1977.

Location of cabin air inlet - The point in the B-747 cabin at which the cabin air is sampled is shown in figure 2. Air is drawn from a 1/4 inch port about 5 feet above the floor in the right-hand outside wall of the staircase to the upper deck (left side of the right-hand aisle). A tetrafluoroethylene (TFE) disk attached to the wall extends the inlet to the port about 1/4 inch from the wall surface. This is to minimize drawing air from along the wall surface into the sample since ozone can be destroyed by contact with surfaces. About 20 feet of 1/4 inch TFE tubing is used between this port and the ozone analyzer

location on the GASP rack at about station 360 below the passenger deck. The Teflon coated tubing was cleaned and found to have negligible loss of ozone.

Example en route simultaneous measurements of cabin and outside ozone - A plot of ozone data taken during a B-747 SP flight is shown in figure 3. Some points to note from this plot are:

1. Atmospheric ozone concentrations vary widely during a flight.
2. A constant difference or ratio between ozone concentrations outside and in the cabin does not exist.
3. On certain occasions ozone in the cabin can read higher than that measured simultaneously outside. This occurs when outside concentrations have decreased from a previous reading. Ozone levels in the cabin that were picked up earlier have not had time to decay to the lower concentration. It was noted during a period of continuous monitoring (measurement update every 20 seconds) that a 2 to 3 minute lag would occur between an outside peak and a corresponding peak showing up later in the cabin.
4. Ozone concentrations in the cabin approach those of the outside as the flight progresses. This may be explained by passivation of ducting with ozone with time during a flight in high ozone concentrations.

Correlations between atmospheric ozone concentrations and cabin ozone levels - The data show that an appreciable fraction of atmospheric ozone is not destroyed by the engine compressor and air circulation system before entering the cabin. The data in figure 4 were obtained from the B-747-100 aircraft during two flights in March and April. On the average, 39% of the atmospheric ozone was not destroyed before it entered the cabin and moved to the cabin ozone measurement air inlet. When averaged separately one flight had 46% and the other flight had 33% entering the cabin air sample inlet. These data indicate that the cabin and atmospheric ozone measurement correlations are quite variable as was pointed out from figure 3. Also, variability of the cabin ozone measurement itself can be expected from cabin conditions such as passenger movement, air circulation, galley activities, or smoke. Thus it is necessary

to average data for an entire flight and several flights to get a meaningful statistical average.

The data in figure 5 were obtained from flights in April, May and June from the B-747 SP. This aircraft has the same engine as the B-747. As the data show, on the average, 82 percent of the atmospheric ozone is not destroyed before reaching the cabin ozone measurement inlet. Once again the data scatter about the average line indicates an effect of the cabin environment and variability of atmospheric ozone.

One method of destroying ozone in air entering the cabin is to heat the sample to higher temperatures. This can be accomplished on the B-747 by taking air for the passenger cabin from the fifteenth compressor stage instead of from the lower temperature eighth compressor stage. An example of the effect such an action produces on cabin ozone is shown in figure 6. For this particular flight only cabin ozone data were available. During this flight of the B-747 SP from New York to Tokyo, the fifteenth stage air was off and on intermittently. Information about the times for which air was taken from the fifteenth stage and which engines were used for this if all four were not, was handlogged by the B-747 SP flight crew and provided to NASA. Note that around 0400 GMT, there is a discrepancy (low cabin ozone with no fifteenth stage air). This may be valid or it may be manual error. It is also worth pointing out that the GASP system records time from its own clock which is independent from the aircraft clock, although effort is made to have both clocks synchronized. The peak in cabin ozone at 0500 GMT is believed to be real. Note that it began during a climb to 43,000 feet.

Since it is known that higher temperatures from the fifteenth compressor stage destroy ozone, data were acquired from several flights which used the fifteenth stage air. Since the crew usually switch back and forth between the eight and fifteenth stages, a signal was added to the GASP data which indicated when the fifteenth stage was being used. These data are shown in figure 7. The average of all data shown is 18% ozone retention, a change of 64 percentage points from figure 5. Calculations of ozone destruction due to the temperature increase in the compressor produce the levels of ozone shown in the figure 7.

Another method of destroying ozone is to reduce the cabin air exchange rate and to recirculate cabin air thus increasing the residence time and possibility for ozone destruction and also reducing the influx of new ozone. Data illustrating the effects of increased recirculation are shown in figure 8 for several flights after the B-747 SP's air circulation system was altered. The average of the data is 55% ozone retention, an improvement of 27 percentage points from figure 5. Figure 9 shows the same conditions of air circulation as figure 8 but with the use of fifteenth stage air. The average is 15% ozone retention, an improvement of 40 percentage points over figure 8 and about the same as figure 7.

The correlations of cabin ozone with atmospheric ozone for the various air conditioning operating conditions on the B-747 SP are summarized in figure 10. The averages (slopes) of each of the curves are for all GASP data which have been analyzed at this time for the air conditioning configurations shown. Other data, showing essentially the same characteristics as in figures 4-9 exist but have not been analyzed. The essential points are that increasing the amount of air recirculation reduces the ozone level in the cabin, the amount dependent upon the amount of recirculation; and that the use of the air from the fifteenth compressor stage reduces the cabin ozone level substantially, the final level being somewhat influenced by the configuration of the air circulation system.

Another method of destroying the ozone is to adsorb it before the air enters the cabin. Data for flights during which the cabin air was continuously scrubbed through a charcoal filter to remove the ozone are shown in figure 11. The air circulation system for these flights was in the same configuration as for figures 8 and 9. In figure 11, the average is about 5% ozone retention, an improvement of 50 percentage points from figure 8. The essential point is that a properly designed, continuous flow absorbtion system, can be more effective in reducing the cabin ozone level than intermittantly taking fifteenth stage compressor air for the cabin. Insufficient data exist at this time to properly evaluate the long-term life and effectiveness of the charcoal system.

Data are and will be acquired to evaluate this system as well as other systems which may be put into service. For comparison, the average slope for the charcoal system is also plotted on figure 10.

Atmospheric Ozone Encounter Statistics

Since March of 1975, the NASA Global Atmospheric Sampling Program (GASP) has been obtaining, archiving and analyzing atmospheric trace constituent data in the lower stratosphere and upper troposphere (ref.1-13) These data are acquired using fully automated sampling systems operating on a United Airlines B-747 (N4711U), a Pan American World Airways B-747 (N655PA), a Pan Am B-747 SP (N533PA), and a Qantas Airways of Australia B-747 (VH-EBE). The objectives of this program are to establish baseline levels and natural variability of selected constituents, and to analyze these data to better understand the physical processes (particularly transport) in the atmosphere and to assess potential adverse anthropogenic effects on the natural atmosphere.

The analyses reported here represent a spin-off from these objectives, and came about when, in the winter of 1977, the airlines received complaints about passenger and crew discomfort during flight. Since it is well known that subsonic aircraft cruise altitudes are sometimes in the stratosphere, and that the likelihood of flight in this region is greatest at mid-to-high latitudes in the winter and spring, ozone was a logical suspect. The analyses in this section are restricted to examining the frequency that GASP-equipped airliners encounter various ambient (atmospheric) ozone levels, to establish the susceptibility of the flights to high levels of cabin ozone.

Data profile statistics - Figure 12 shows the distribution of GASP ozone measurements, by aircraft and month, for data obtained from March 1975 through December 1976. There are a total of 31263 observations represented here, with 30.7, 34.3, 24.5 and 7.6 percent of these from N4711U, N655PA, N533PA and VH-EBE respectively. The total number of observations is distributed nearly evenly among the four quarters (17-31 percent each), but it should be noted that N4711U is the only aircraft from which data are available for all months.

The distribution of the GASP ozone observations by latitude is shown in figure 13a. This distribution reflects the route structure of the GASP-equipped aircraft. Since this figure is based on all observations reported through December 1976, it includes the effect of the addition of new GASP aircraft; for example, data from the Pan Am B-747 SP were available for the first time in April 1976, and the first Qantas data were reported in the third quarter of 1976. The distribution of the data by geopotential altitude is shown in figure 13b. Approximately 80 percent of the GASP observations are between 33,000 and 41,000 ft. (10.0-12.5 km). This distribution does not vary appreciably between the contributing aircraft, except that data above 12 km are mostly from the B-747 SP.

Analyses - GASP observations are in the upper troposphere or lower stratosphere depending on whether the aircraft is below or above the tropopause (ref. 2,3,5,7,8,10). The GASP mean ozone levels, as a function of the difference between the tropopause pressure and the ambient pressure show the expected (ref. 14) rapid increase in ozone levels above the tropopause (ref. 6, 13). The altitude range of the GASP measurements includes most of the altitudes through which the height of the tropopause varies. Since the tropopause height generally decreases with increasing latitude, and is lowest in the spring (Northern Hemisphere), mean ozone levels increase with latitude (figure 14), and are highest in the spring (figure 15). Here GASP data for 1975-76 at pressure altitudes from 10.5-11.5 km are shown by the solid curves. Measurements from the North American ozonesonde network are shown by the dashed lines (ref. 15, 16). The shaded areas indicate $\pm$ one standard deviation from the GASP mean values, and reflect the large natural variability of ozone in the altitude range of the GASP observations. Mean ozone levels also generally increase with altitude, but, as with the latitudinal and seasonal variations, the standard deviations from the mean values are large, since the means are a mix of tropospheric and stratospheric observations depending on local meterological conditions.

In figure 16, the bimonthly distribution of mean ozone levels, by aircraft also shows the annual cycle. Note that here, as in figure 15, the GASP data are shown as bimonthly averages plotted monthly; i.e. Jan.-

Feb. is the average of data in Jan. and Feb., Feb.-Mar. is the average of data in Feb. and Mar. etc. The curves for the standard B-747's (N4711U, N655PA, and VH-EBE) are comparable even though the route structures of the airlines are quite different. Mean ozone levels from the B-747 SP measurements are consistently higher than those from the other aircraft. The dominant factor here is most likely the differences in flight level - the mean altitude from the SP observations is 4000 ft. (1200 m) above the mean altitude for observations from the other aircraft. However, routing may be a significant factor also since the SP is used frequently on long flights at northern latitudes.

In figures 17-20, the GASP data are examined in a different format, which shows, by aircraft, for any given level of ambient ozone, say 03, the fraction of the observations for which the ozone level was greater than 03. Because the distributions are expected to be seasonally dependent, and because data are not available from all GASP-equipped aircraft for all seasons (see figure 12), the data have been analyzed by calendar quarters. In the first quarter (figure 17), the data from the United B-747 (N4711U) and the Pan Am B-747 (N655PA) show that the fraction of ozone observations greater than 100 ppbv for these aircraft was about the same, but that N655PA encountered ambient ozone in the range 200-400 ppbv more frequently than did N4711U.

Data from the Pan Am B-747 SP (N533PA) are available for the second, third and fourth quarters (figures 18-20). The cumulative ozone frequency distributions for N533PA show that this aircraft encountered stratospheric ozone levels much more frequently than did the standard B-747's. This may be attributed to the higher altitudes typical of SP flights, as well as the greater frequency of flights at high latitudes. The N533PA distribution for the fourth quarter (figure 20) has a discernably different shape than do the N533PA distributions for the second and third quarters (figures 18 & 19). This most likely reflects the expansion of the route structure of the aircraft to include flights from the U.S. west coast to the South Pacific and from the U.S. east coast to South America.

A comparison of figure 18 with figures 17, 19 and 20 reveals that the GASP-equipped airliners generally encountered stratospheric ozone levels more frequently in the second quarter than in the first, third or fourth quarters. An exception to this is N655PA which encountered ozone levels more frequently in the first quarter. The routing of the airliner to southern routes during the second quarter where ozone levels are lower influenced this result. Figure 21 provides a direct comparison of the four quarters with the annual mean for N4711U.

The bimonthly variation in frequency of encounters for ozone above several levels is shown, for N4711U, in figure 22. For inter-aircraft comparison, the contours for ozone $\geq$ 200 ppbv from figure 22 are repeated in figure 23 with similar contours for the other aircraft. These distributions support the observation made previously, that encounter frequencies for the standard B-747's are comparable, but that the B-747 SP saw substantially higher ozone levels.

The statistics of ambient ozone encounters presented above can be augmented to include the duration of exposure to various ozone levels during a given flight. GASP data are archived by flight between departure and destination airports. Thus time histories of ozone exposure levels could be obtained from GASP data, if required, to better define the problem. An example of this is a selected high ozone concentration encounter shown in figure 24. During this flight the ambient ozone peaked above 1200 ppbv. The aircraft was in the lower stratosphere with ozone measuring 700 to 800 ppbv prior to this peak. A climb to a higher cruise altitude penetrating deeper into the stratosphere produced the higher concentration as would be expected.

CONCLUDING REMARKS

Considerable effort has been required to acquire airborne ozone instrumentation certified for automatic unattended operation on commercial airliners. Also, much care was taken to provide accurate results.

Simultaneous measurements of atmospheric ozone and ozone levels in the cabin are necessary in evaluating the cabin ozone problem because of (1) the natural wide variability of atmospheric ozone and (2) the large differences found in the ratio between ozone in the cabin and that existing outside.

In cabin ozone measurements made simultaneously with atmospheric measurements and expressed as an average percent of the atmospheric concentrations gave the following results:

1. B-747-100, 39%
2. B-747 SP, 82%
3. B-747 SP with changes in the cabin circulation system, 55%
4. B-747 SP with high temperature fifteenth stage compressor bleed, 18%.
5. B-747 SP with cabin air through a charcoal filter, 5%. (Long-term life not evaluated).

In examining the frequency that GASP-equipped airliners encounter various atmospheric ozone levels, and thereby establishing the potential of these aircraft to encounter high levels of cabin ozone, the following results were found:

1. The frequency of encounters from March 1975 through December 1976 varied substantially with season. The maximum encounter frequencies occurred in the spring for the Northern Hemisphere.
2. Encounter frequencies for the B-747-100's equipped with GASP are comparable, even though the route structure of the airliners are quite different.
3. The B-747 SP encountered higher ozone levels than did the B-747 - 100's. This is most likely a result of the higher operating altitudes of the SP, although routing may be a significant factor also, since, during the period of SP ozone data, the aircraft was operated predominately on long flights at northern latitudes.

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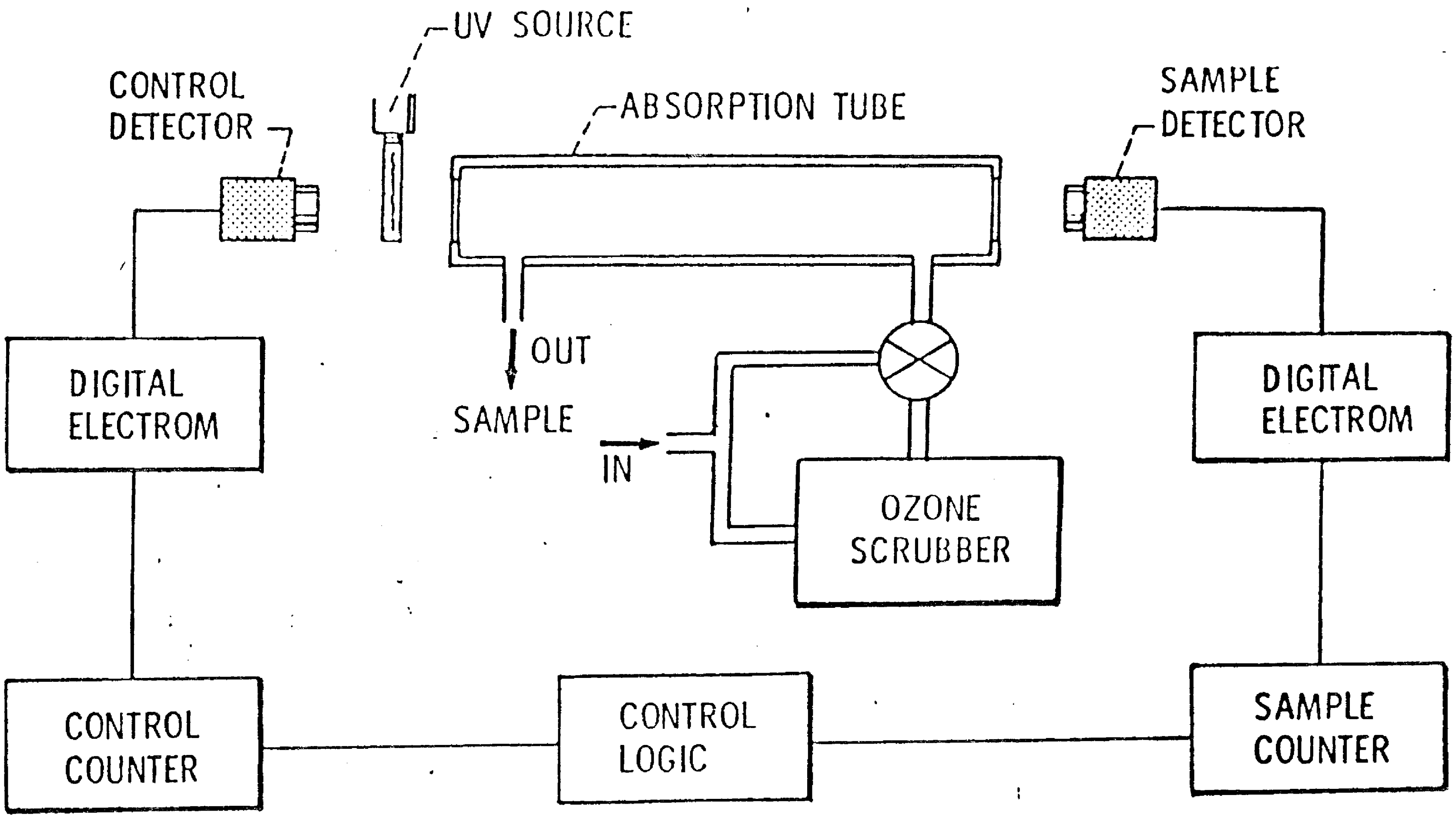

Figure 1. - Block diagram of GASP ozone instruement

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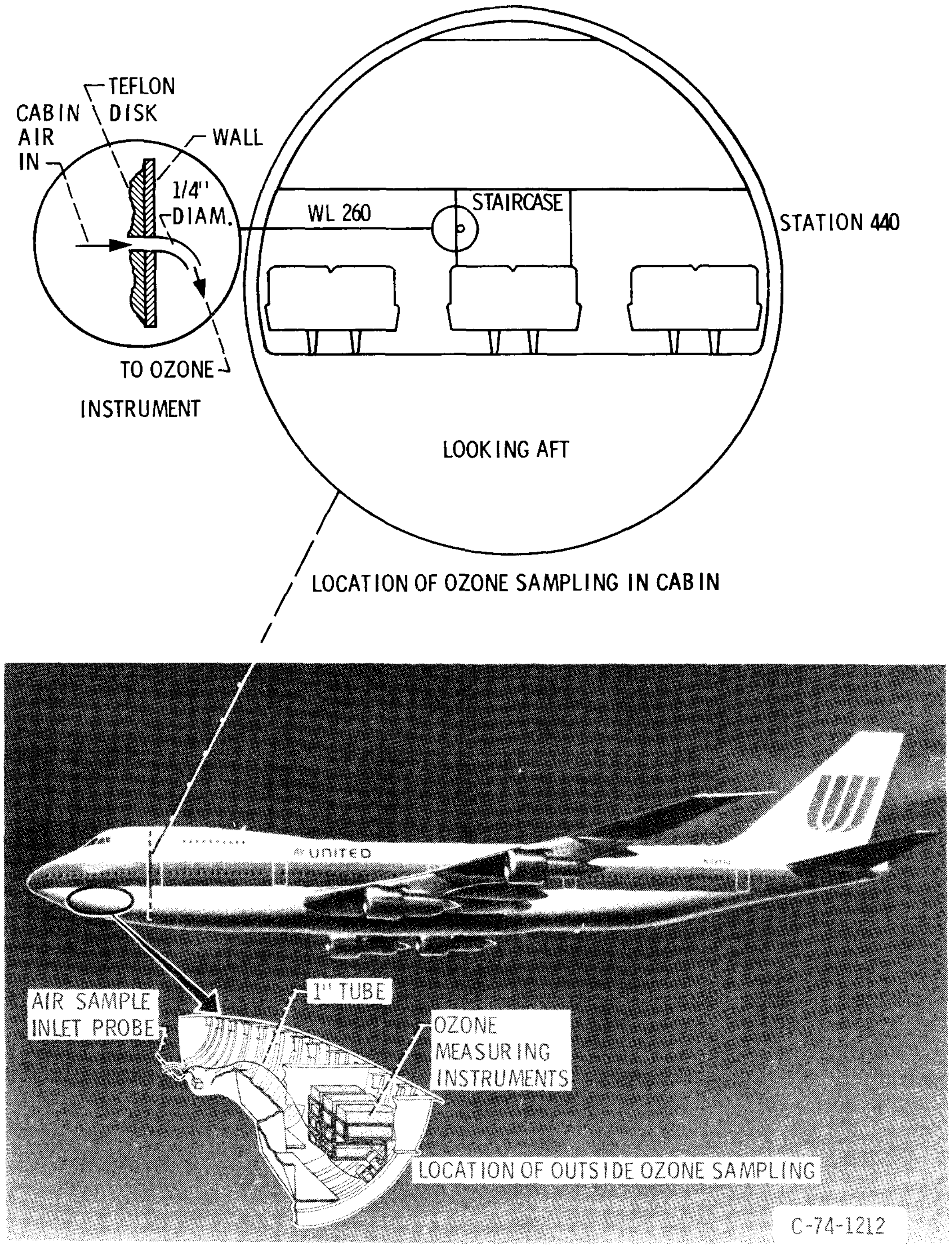

Figure 2. - Ozone measurement locations on B747 airliner.

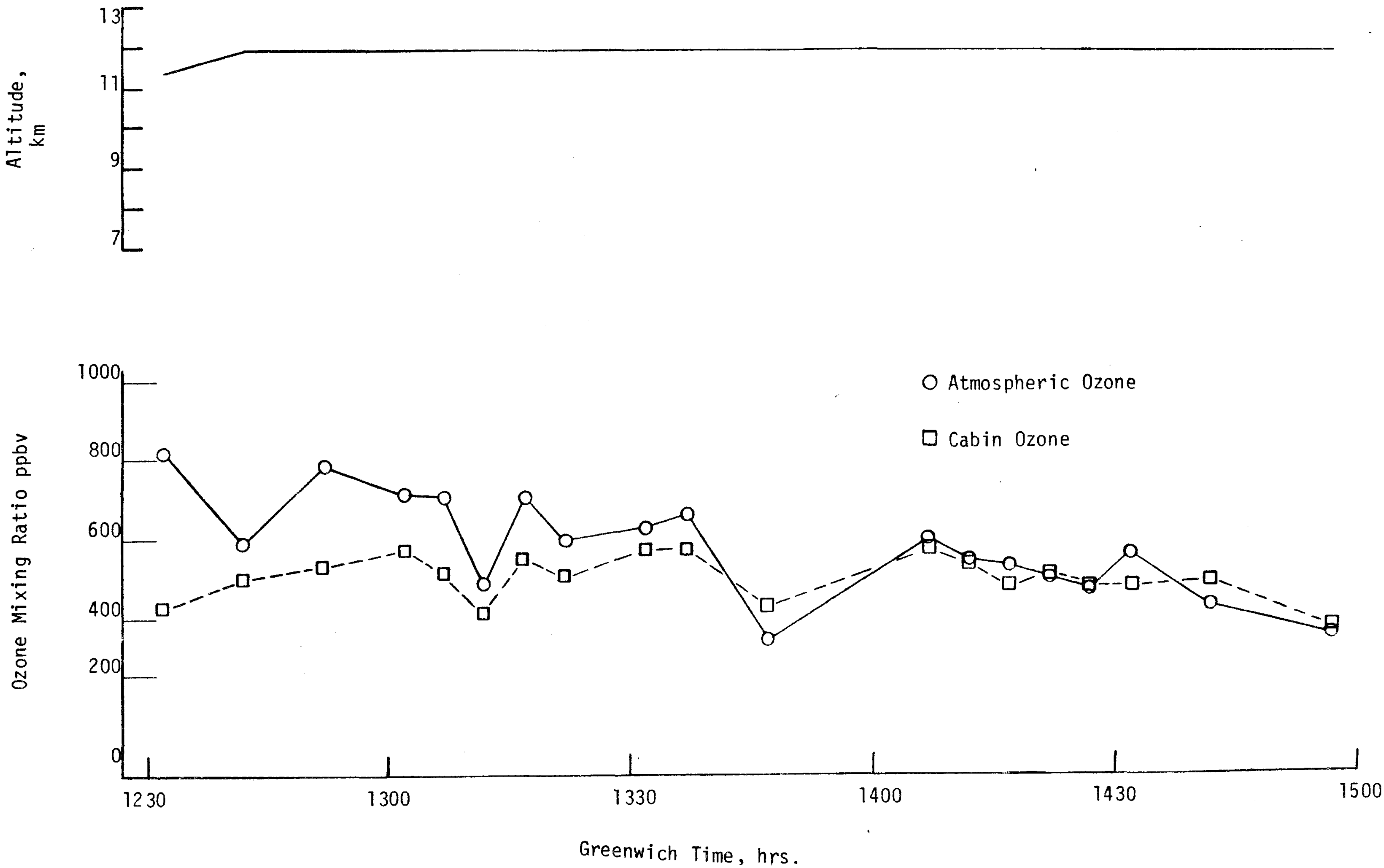

Figure 3. - Time history of cabin and atmospheric ozone mixing ratio levels.

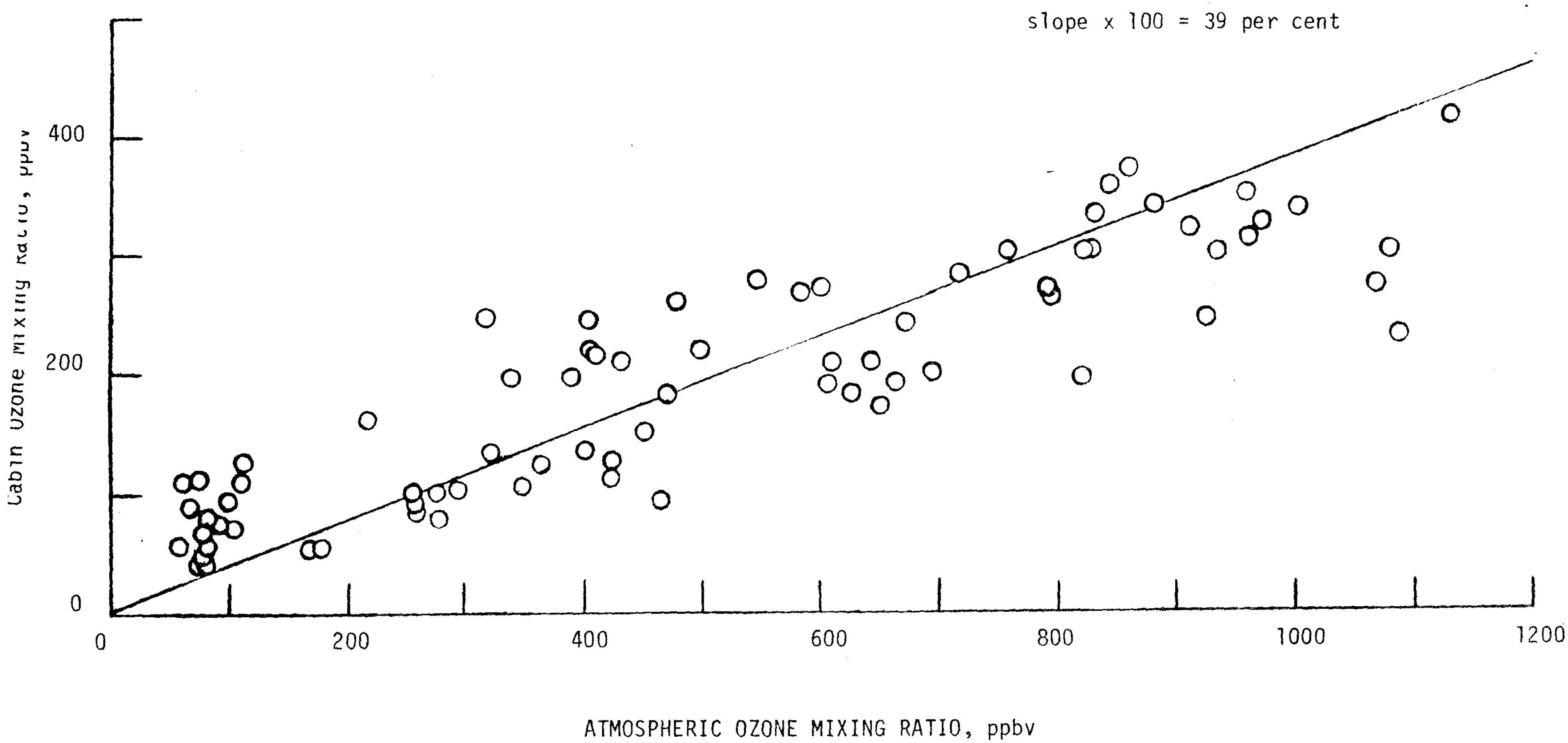

Figure 4. - Correlation of cabin and atmospheric ozone mixing ratios. Data are from March and April 1977, from a B-747 (100).

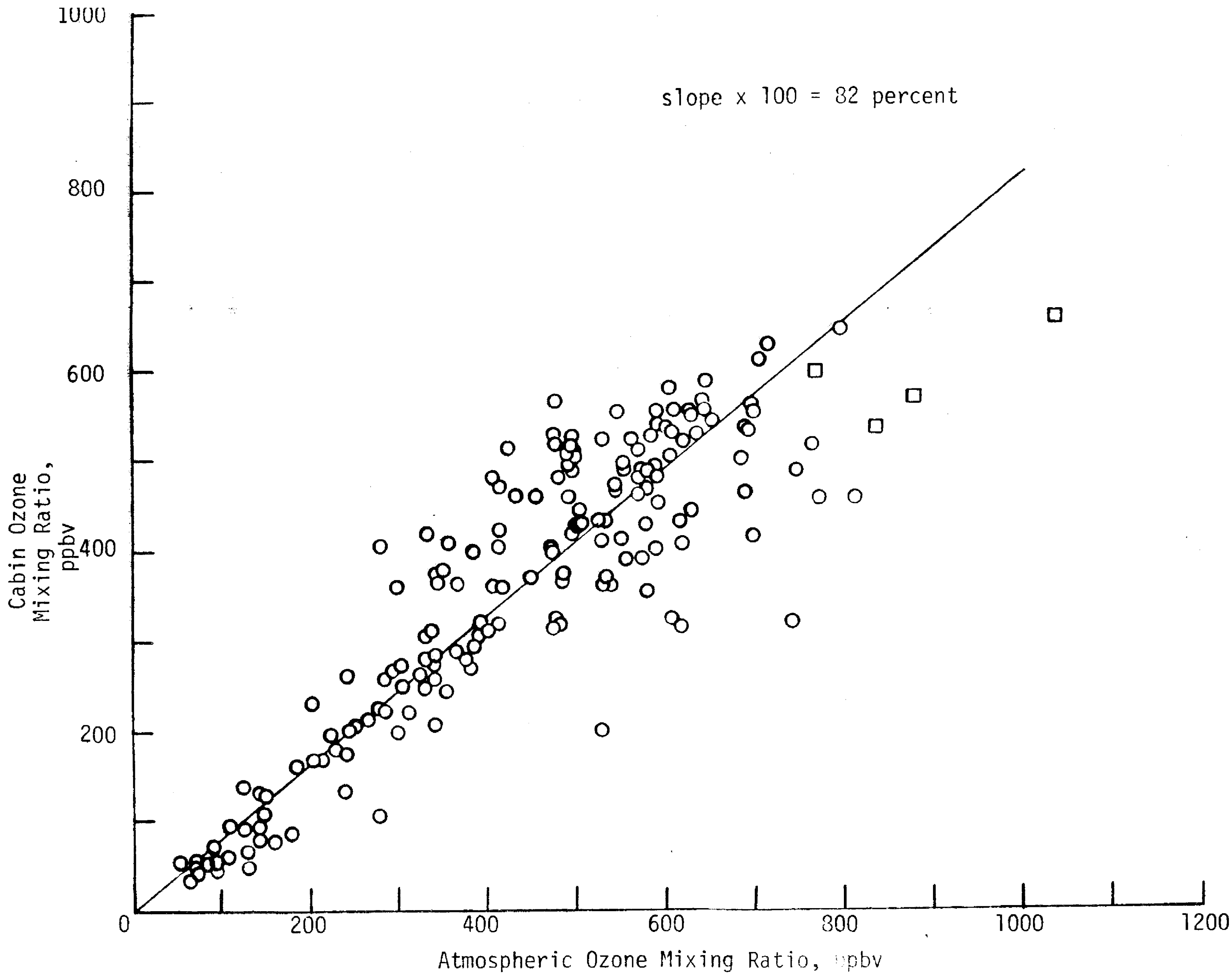

Figure 5. Correlation of cabin with atmospheric ozone mixing ratios. Data were obtained during April, May, June 1977 before changes were made to the B-747SP air circulation system. Squares in the figure show data taken in April.

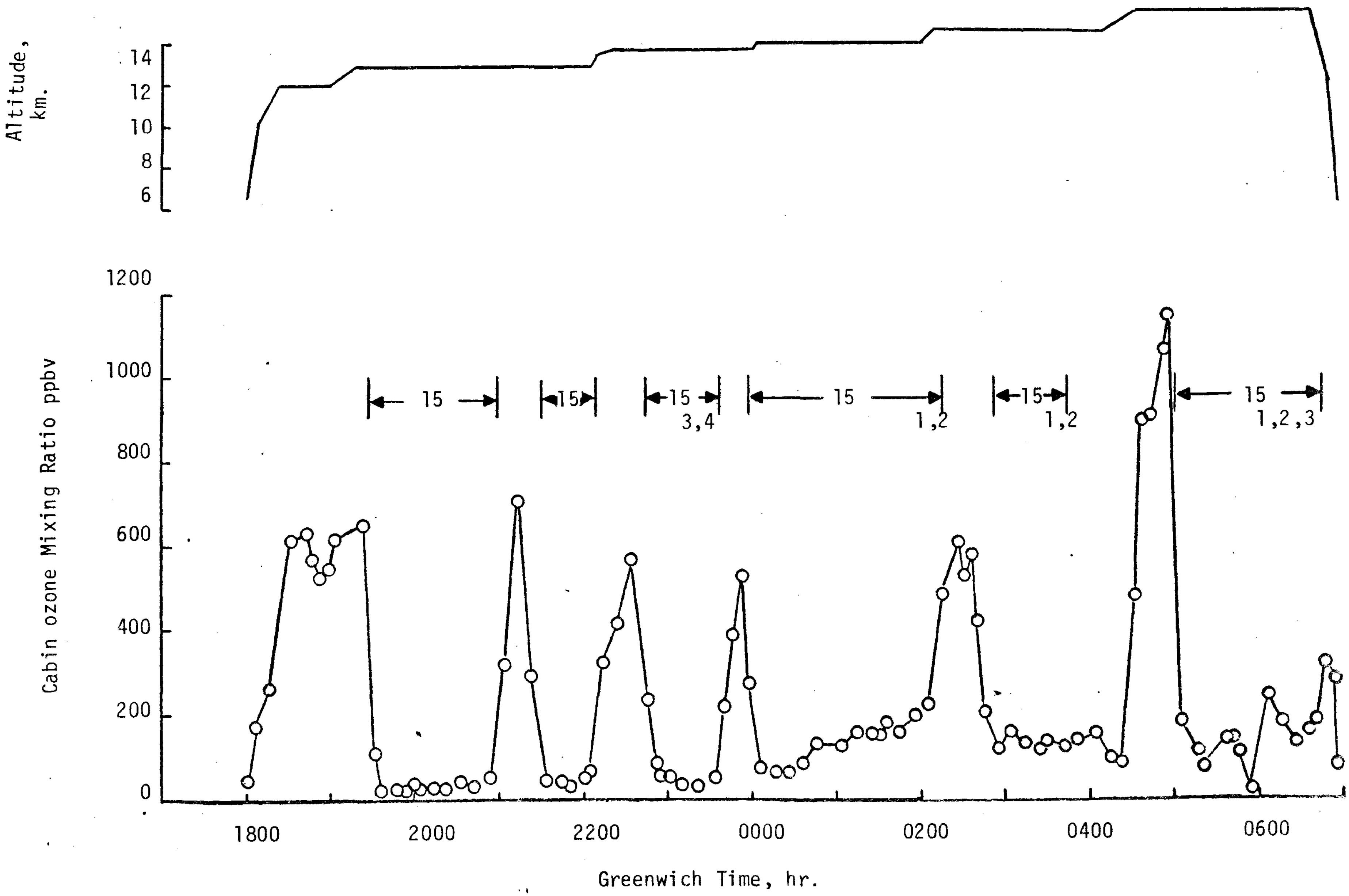

Figure 6. - Effect of 15th stage compressor air on cabin ozone levels. The bracketed data show periods of 15th stage usage and which engines were used, if all four were not used.

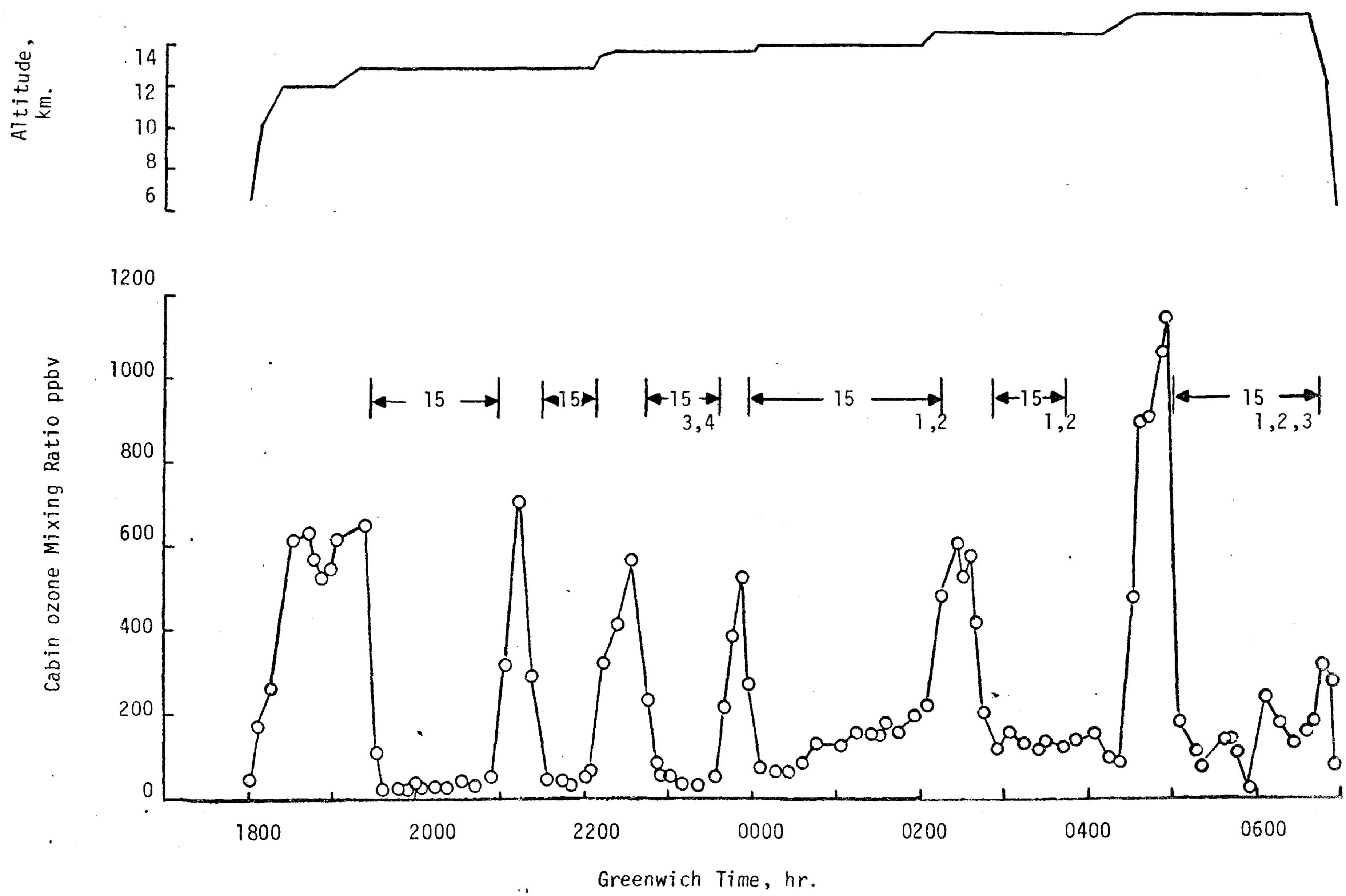

Figure 6. - Effect of 15th stage compressor air on cabin ozone levels. The bracketed data show periods of 15th stage usage and which engines were used, if all four were not used.

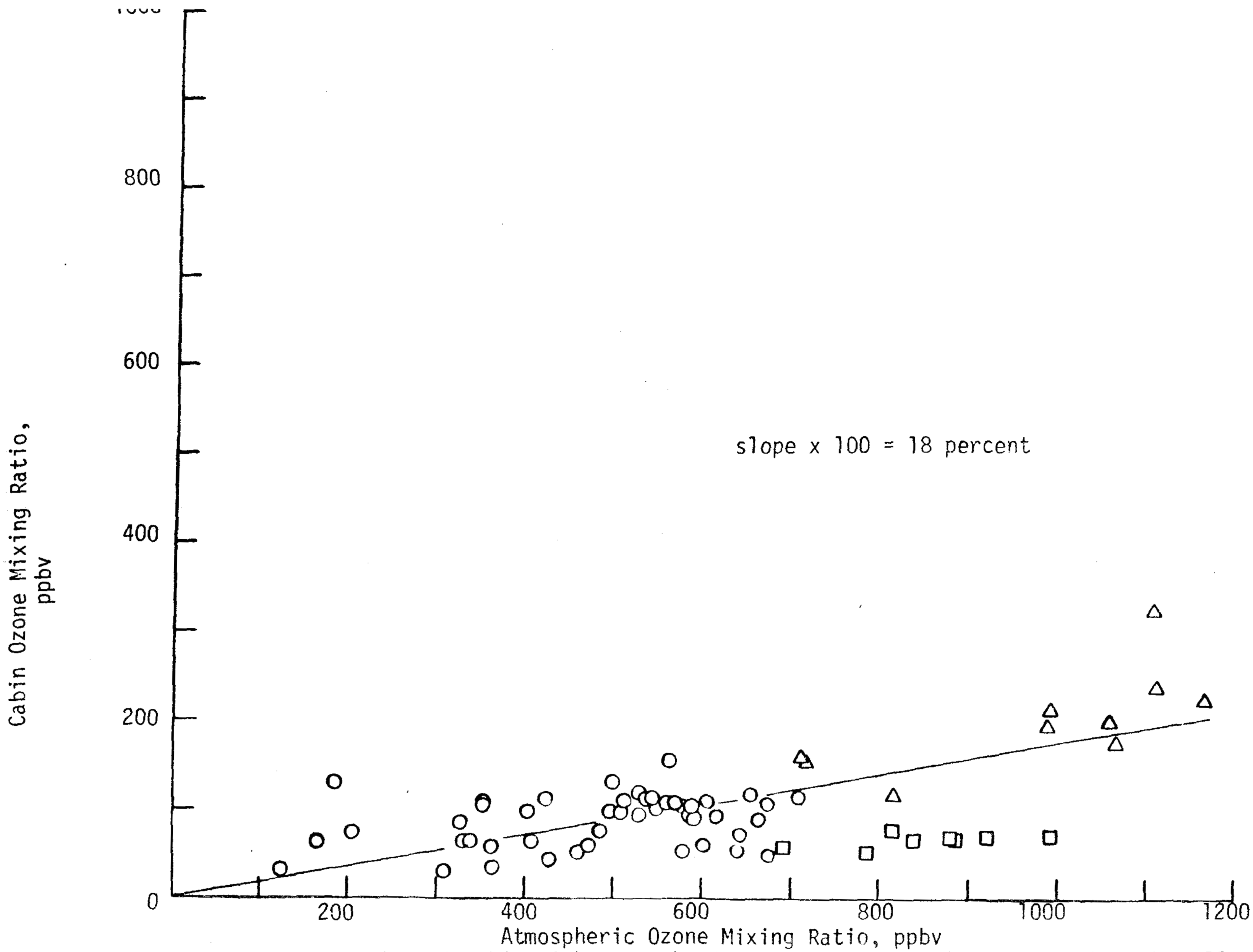

Figure 7. Correlation of cabin with atmospheric ozone mixing ratios. Data show the effect of using fifteenth stage compressor air in the unmodified air system. Data were obtained in April, May and June. The squares and triangles are data from April and May respectively.

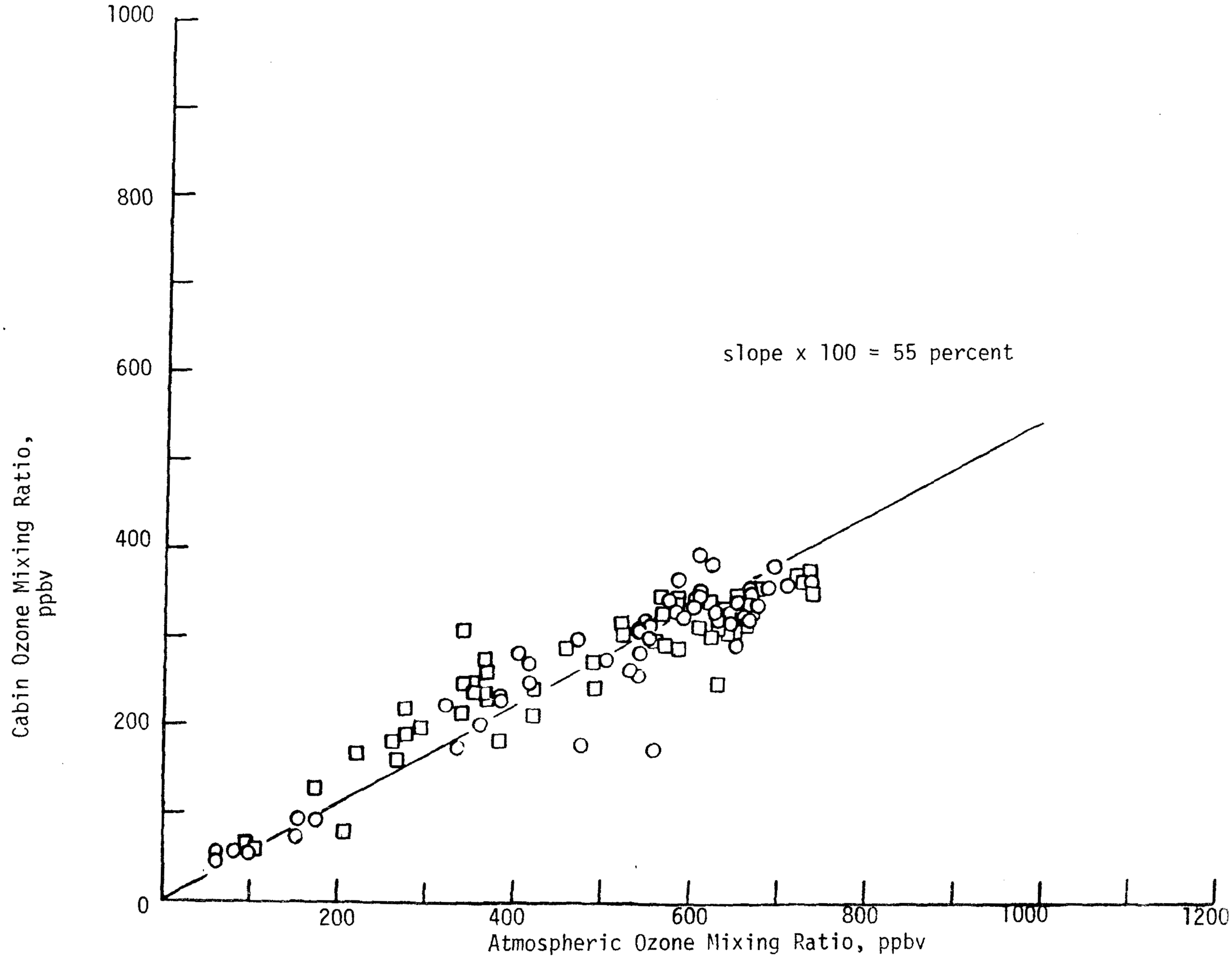

Figure 8. Correlation of cabin and atmospheric ozone mixing ratios. Data are from June 1977 after modifications were made to air systems. The circles and squares show atmospheric

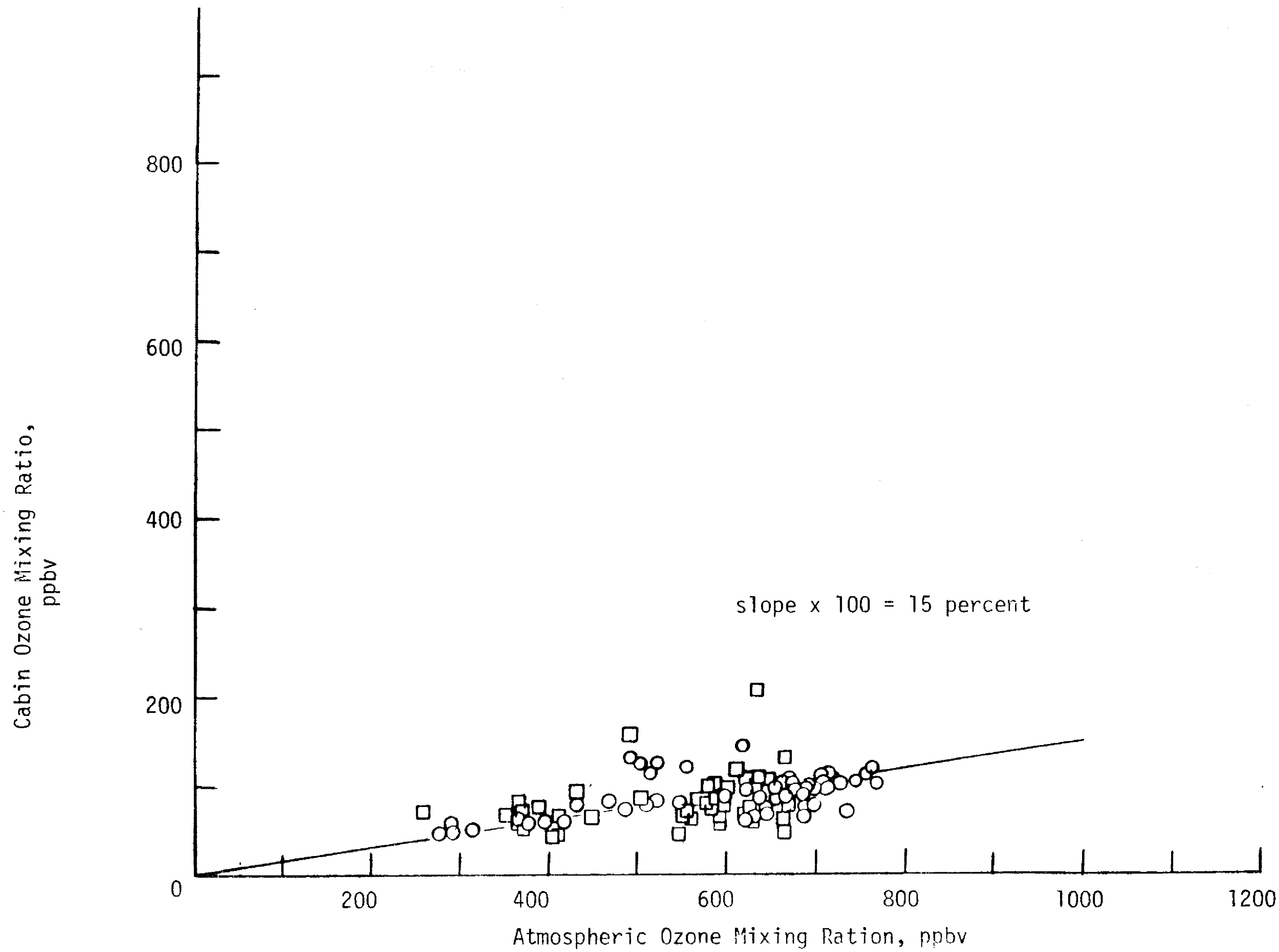

Figure 9. Correlation of cabin and atmospheric ozone mixing ratios. Data show the effect of using fifteenth compressor stage air in the modified air system. The circles and squares show atmospheric ozone data from two different instruments.

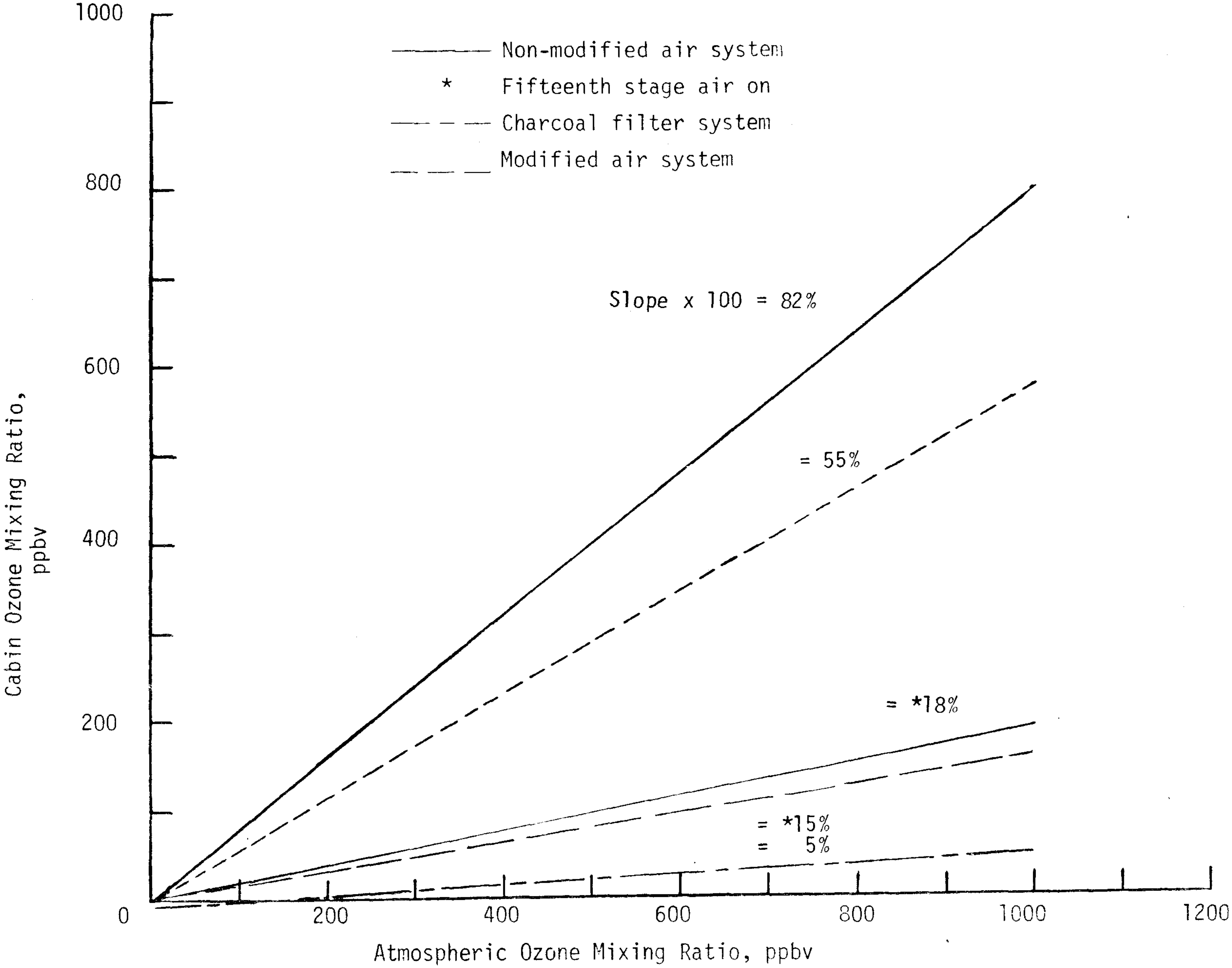

Figure 10. Correlation of cabin and atmospheric ozone mixing ratios, summarizing the effects various aircraft systems have on the cabin ozone mixing ratio level.

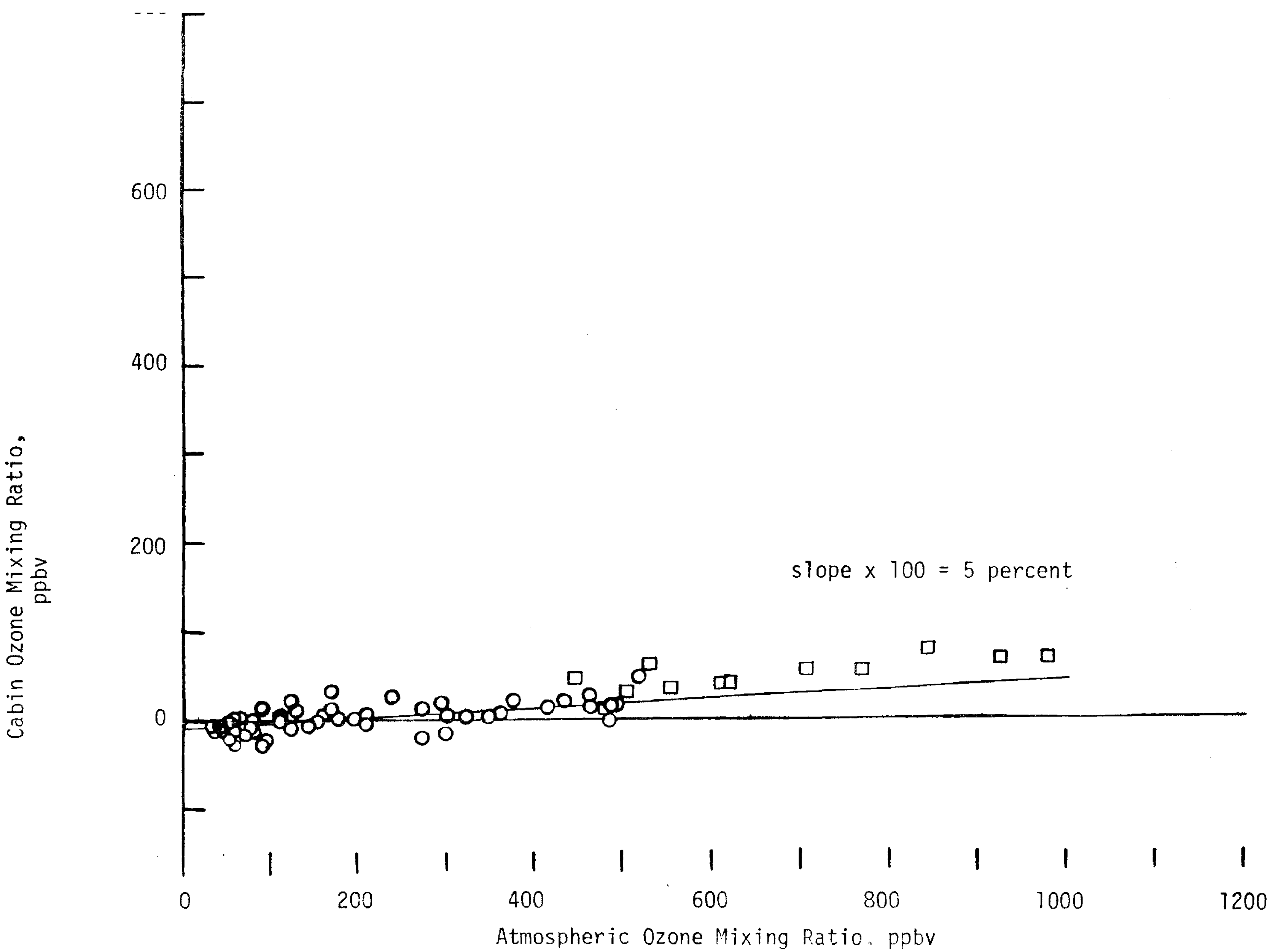

Figure 11. Correlation of cabin and atmospheric ozone mixing ratios. Data show the effect an aircraft charcoal filter system has on cabin ozone levels, circles show data from June 1977. The squares show data from October 1977 in Antartic stratosphere.

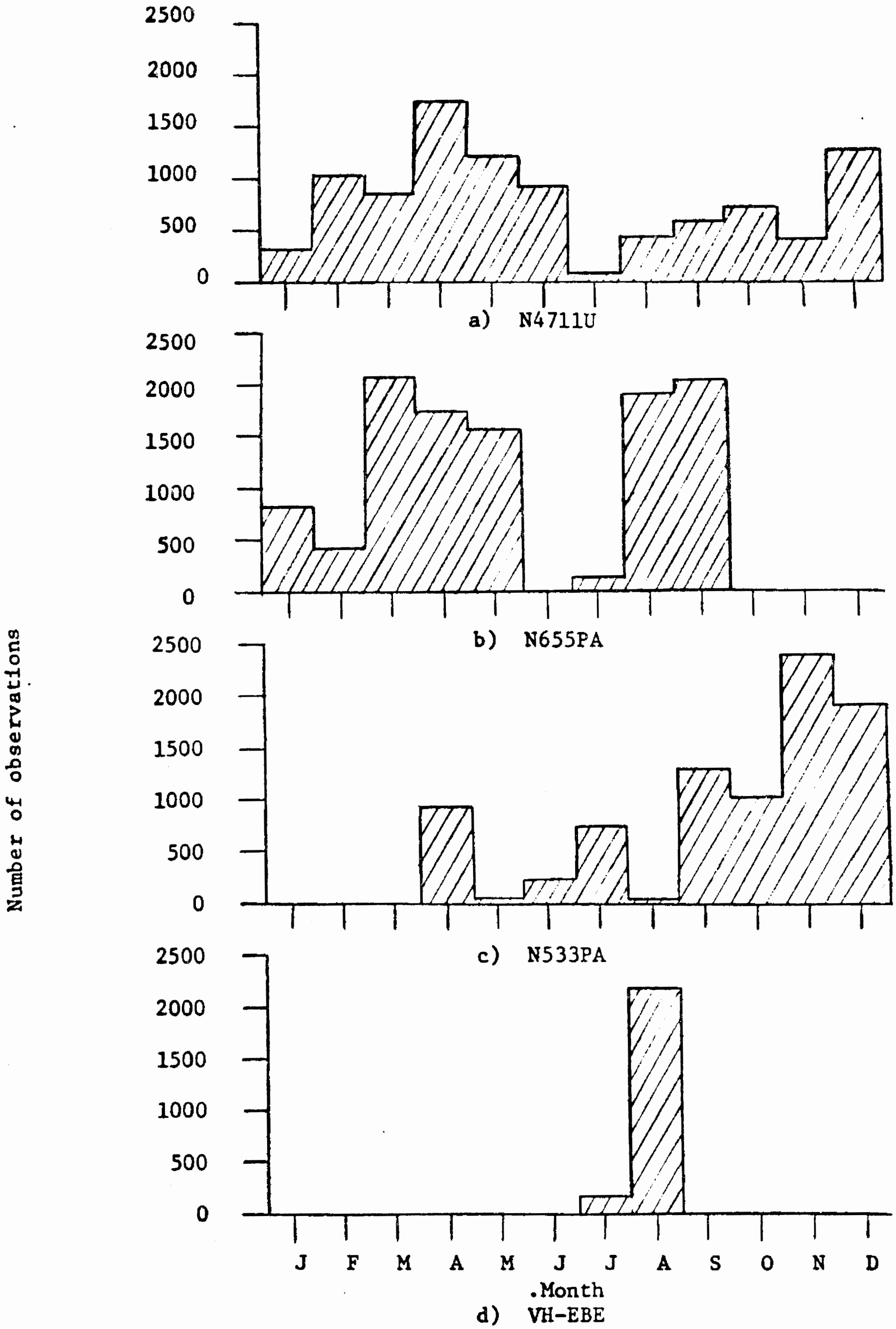

Figure 12.- Distribution of GASP ambient ozone data on tapes VL0001-VL0007 by aircraft

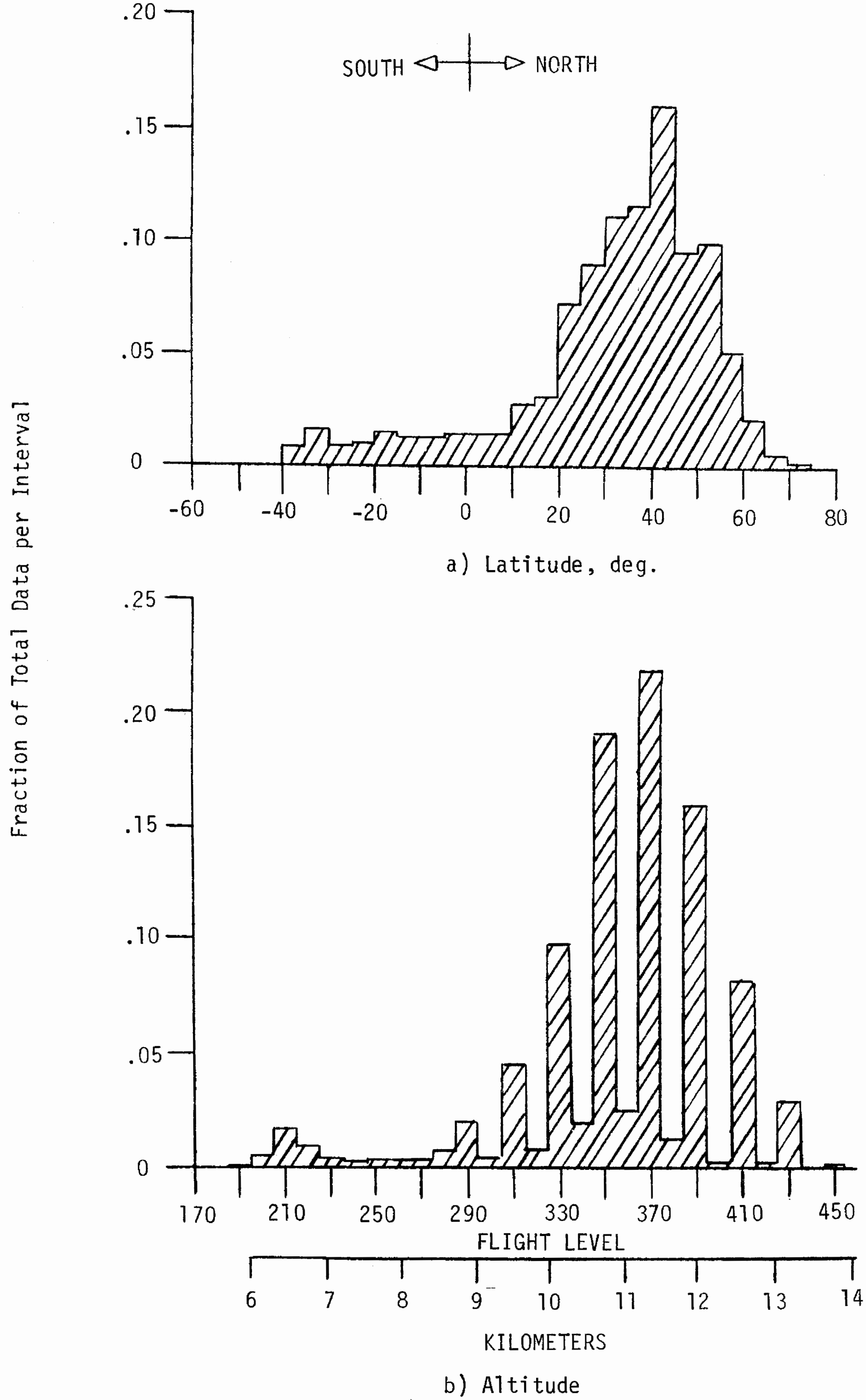

Figure 13. Distribution of GASP ambient ozone data on tapes VL0001 - VL0007 by latitude and altitude.

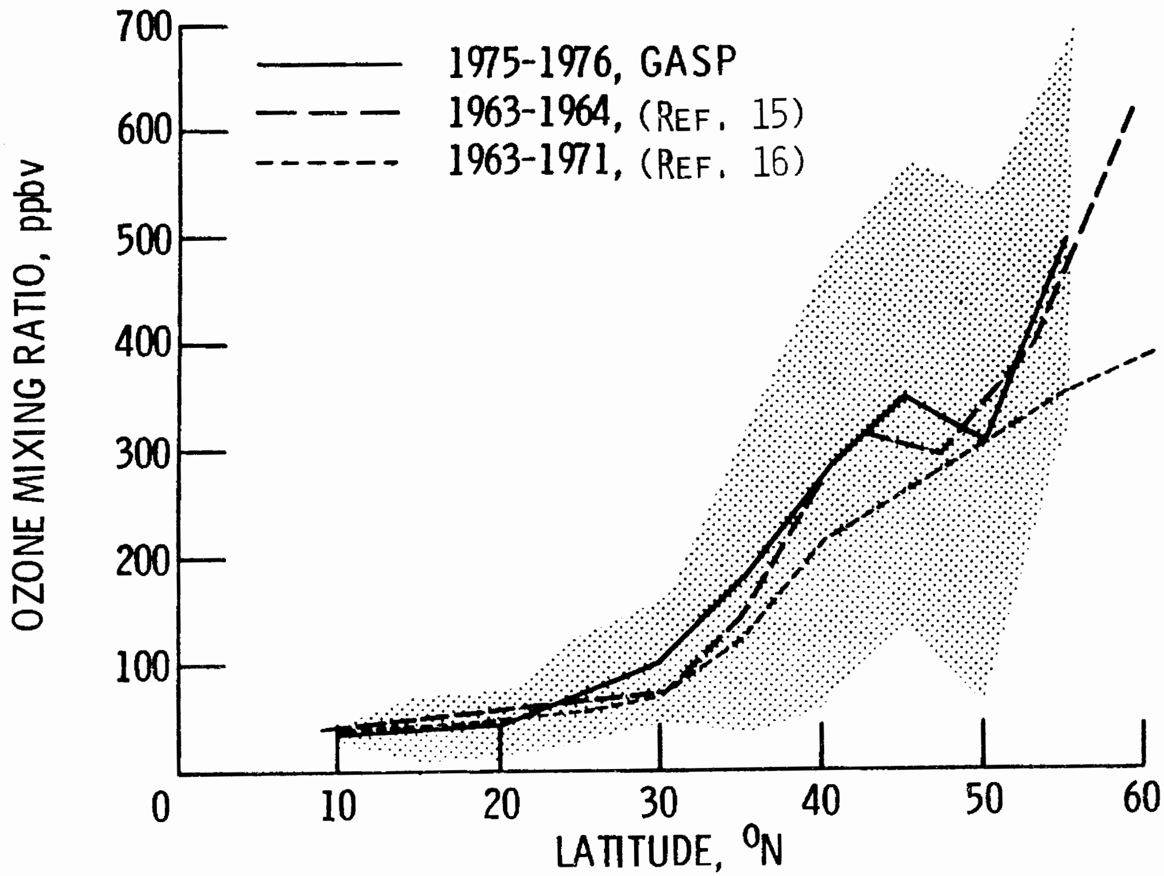

Figure 14. - Latitudinal ozone distribution for March; pressure-altitude 10.5 - 11.5 km.

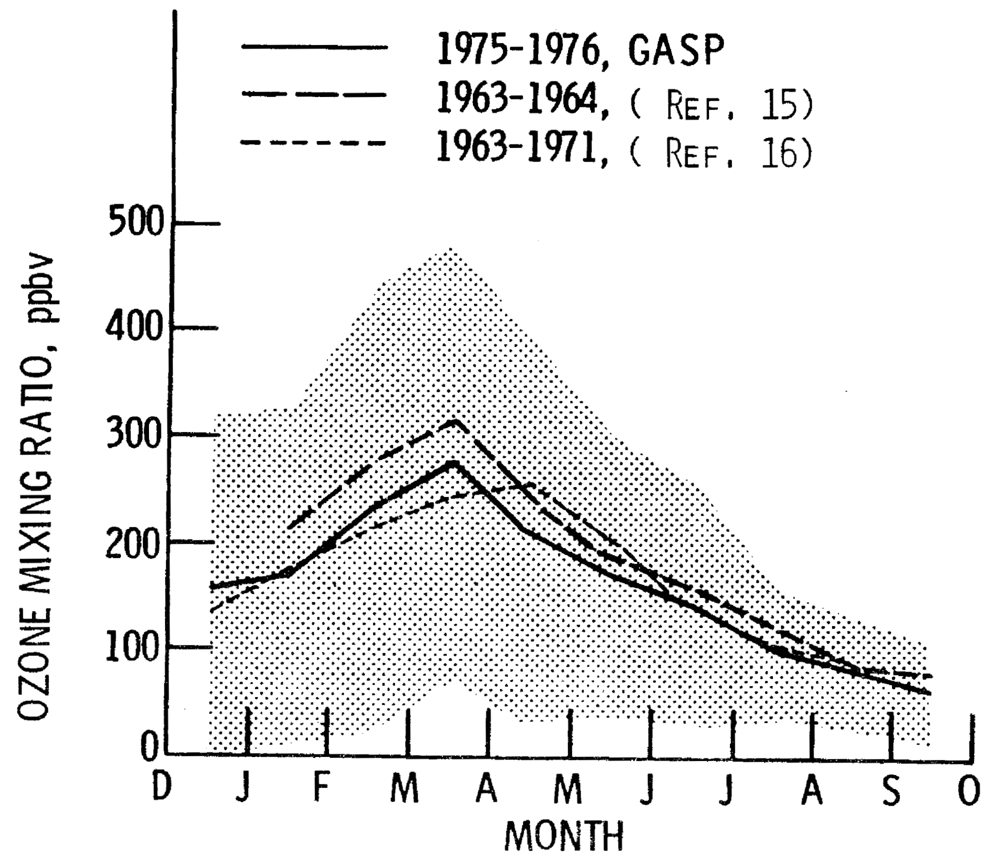

Figure 15. - Bimonthly ozone distribution for 37.5 - 47.5 N latitude; pressure altitude 10.5 - 11.5 km.

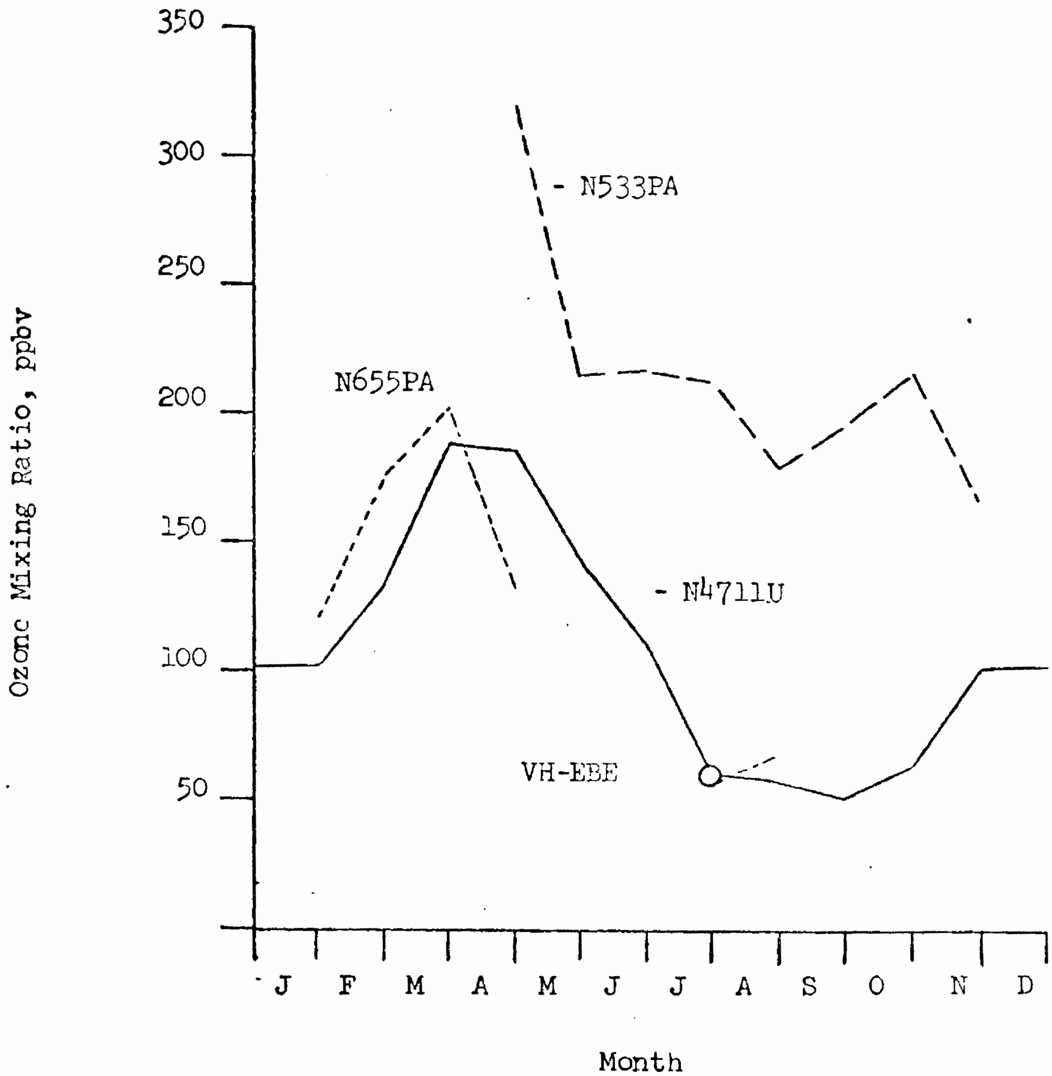

Figure 16. - Bimonthly Mean Ambient Ozone by Aircraft

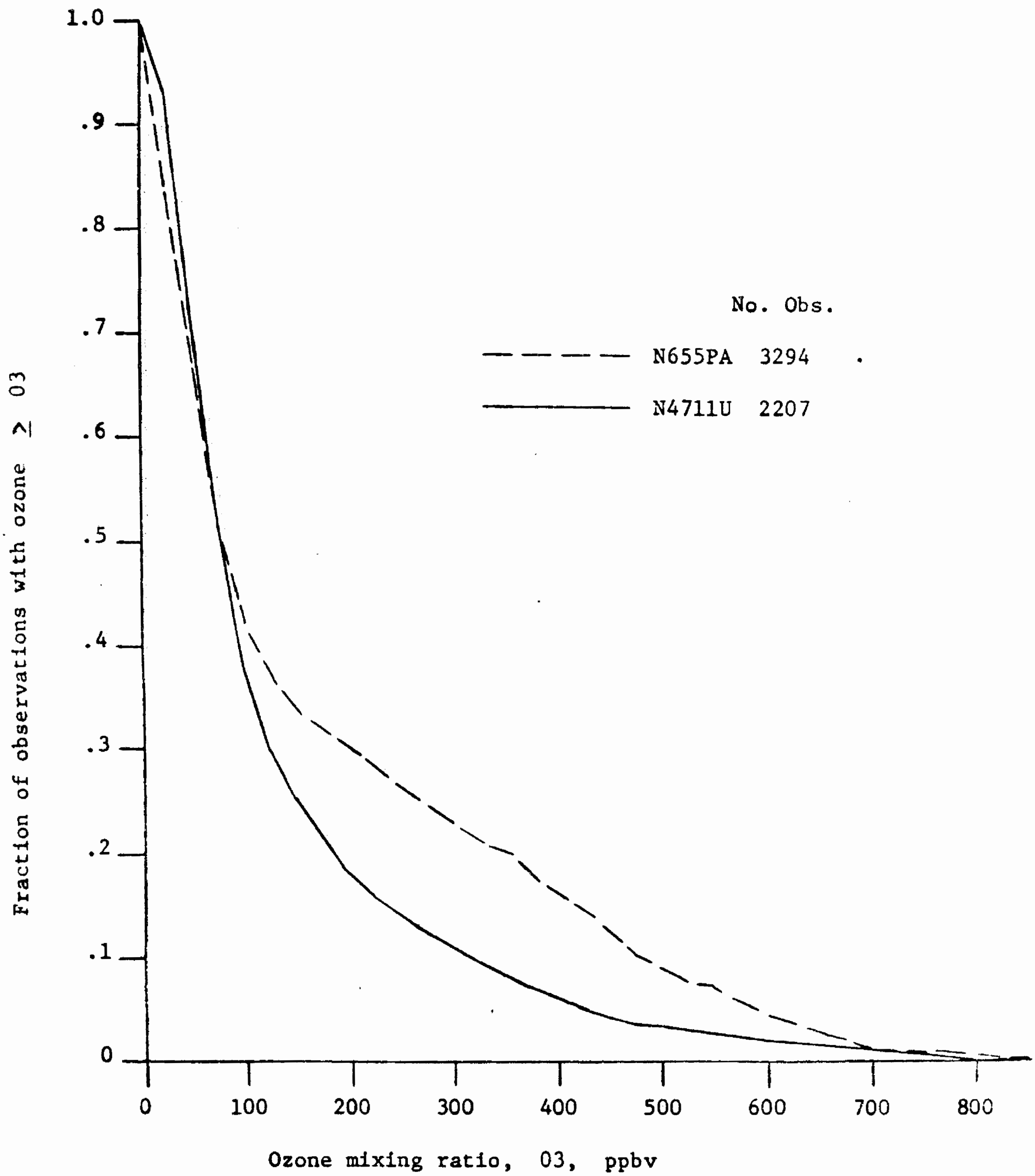

Figure 17.- Cumulative ambient ozone frequency distribution for 1st quarter (Jan-Feb-Mar)

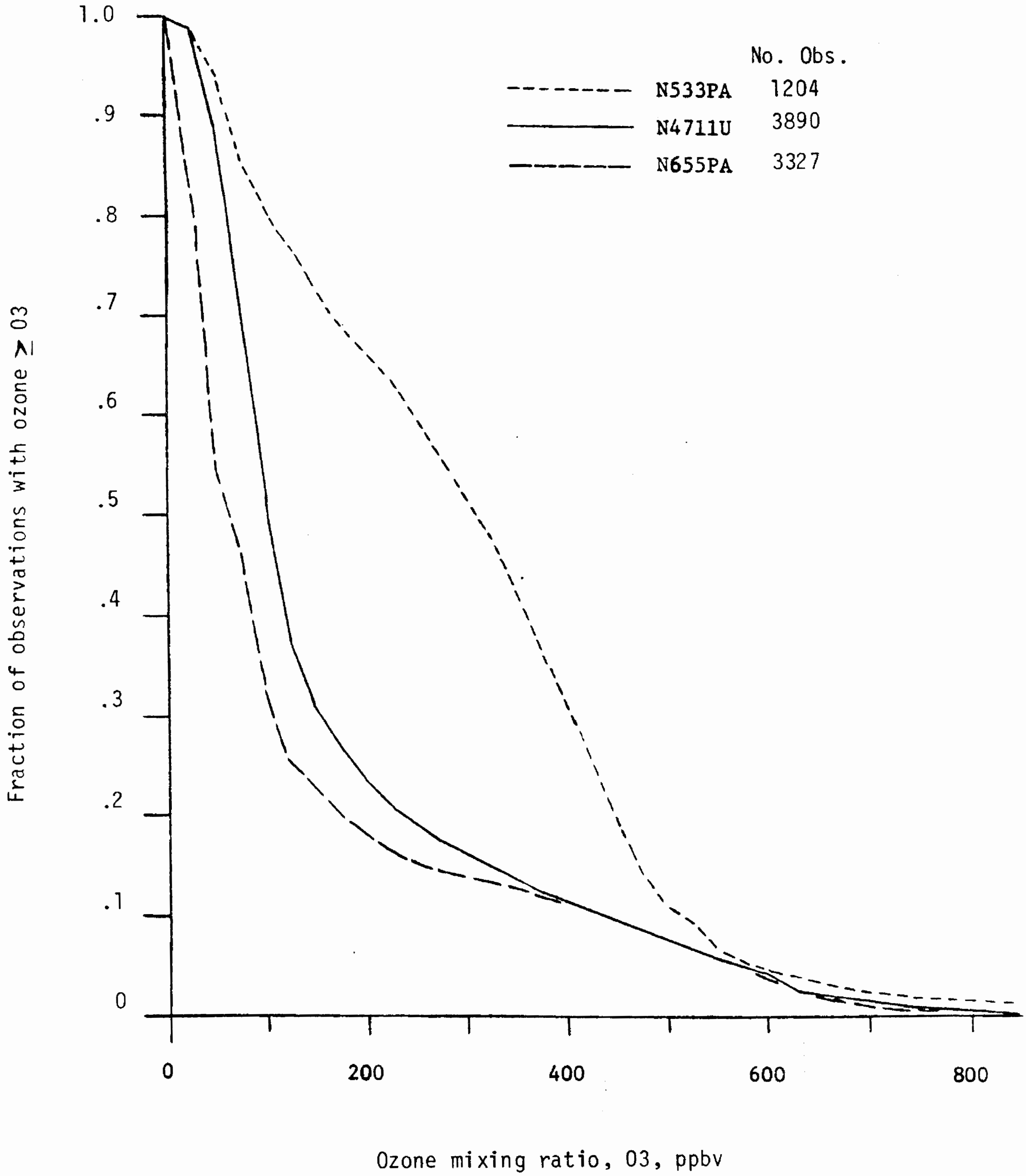

Figure 18. - Cumulative ambient ozone frequency distribution for 2nd quarter (Apr-May-Jun)

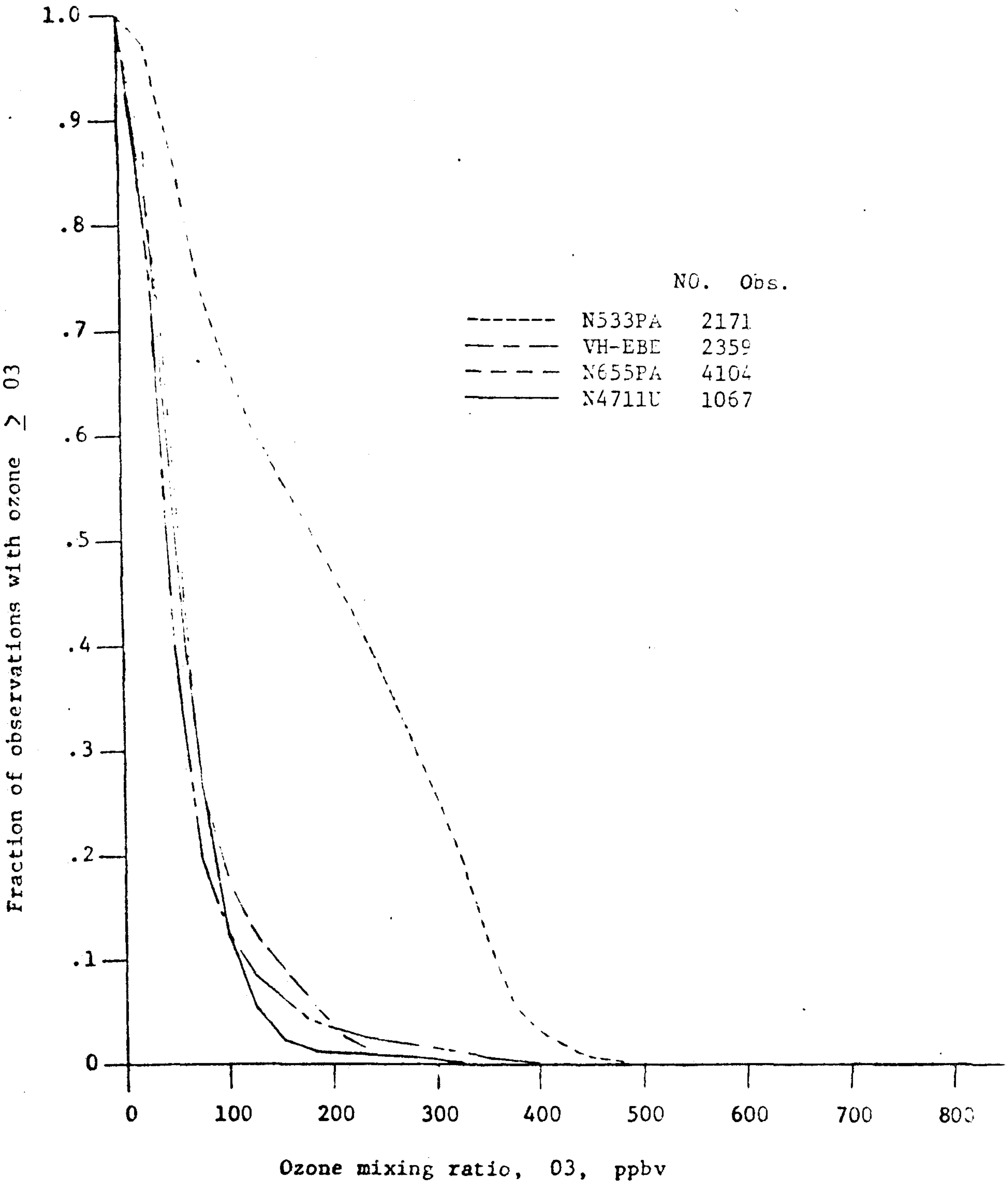

Figure 19.- Cumulative ambient ozone frequency distribution for 3rd quarter (Jul-Aug-Sep)

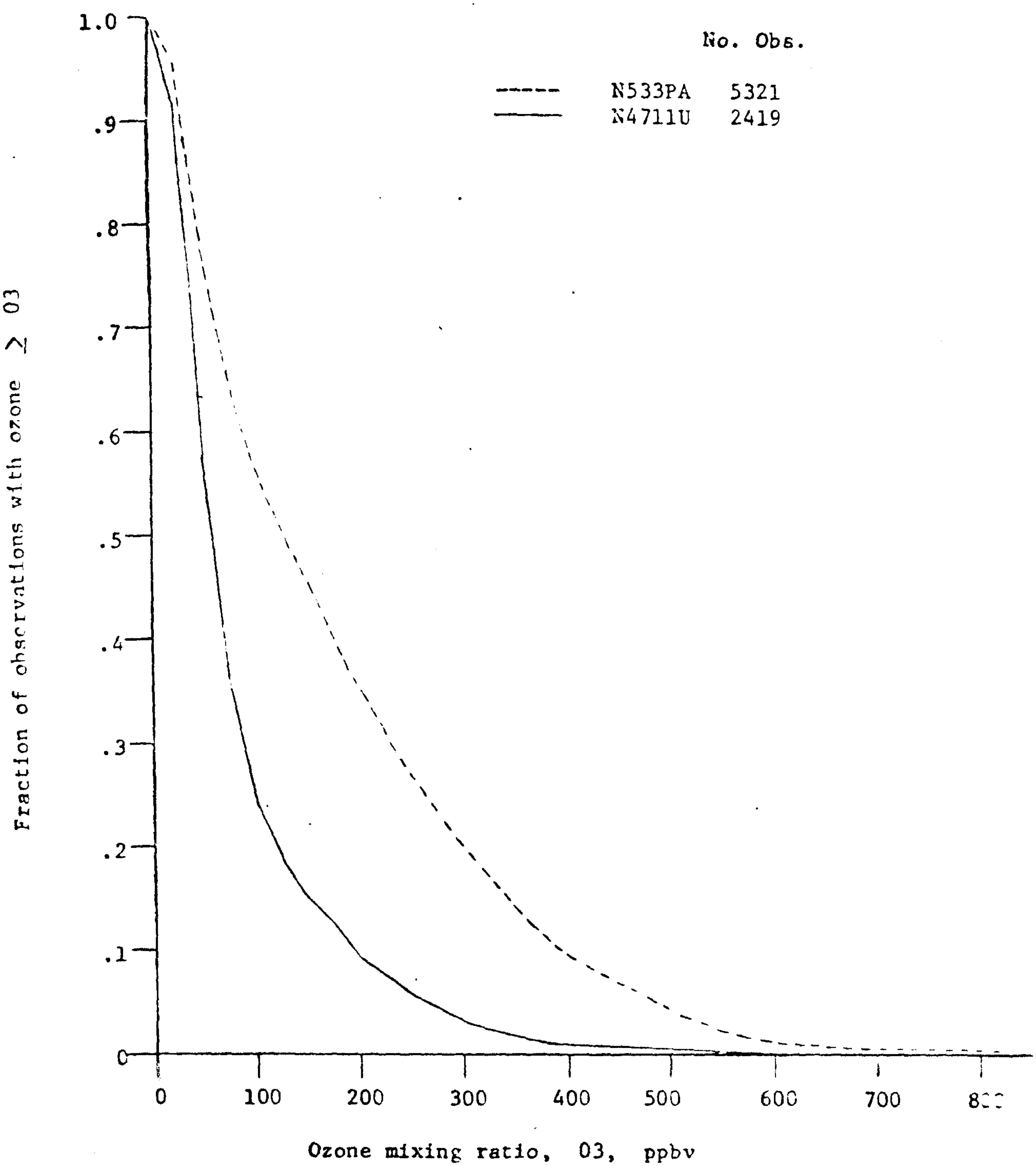

Figure 20.-Cumulative ambient ozone frequency distribution for 4th quarter (Oct-Nov-Dec)

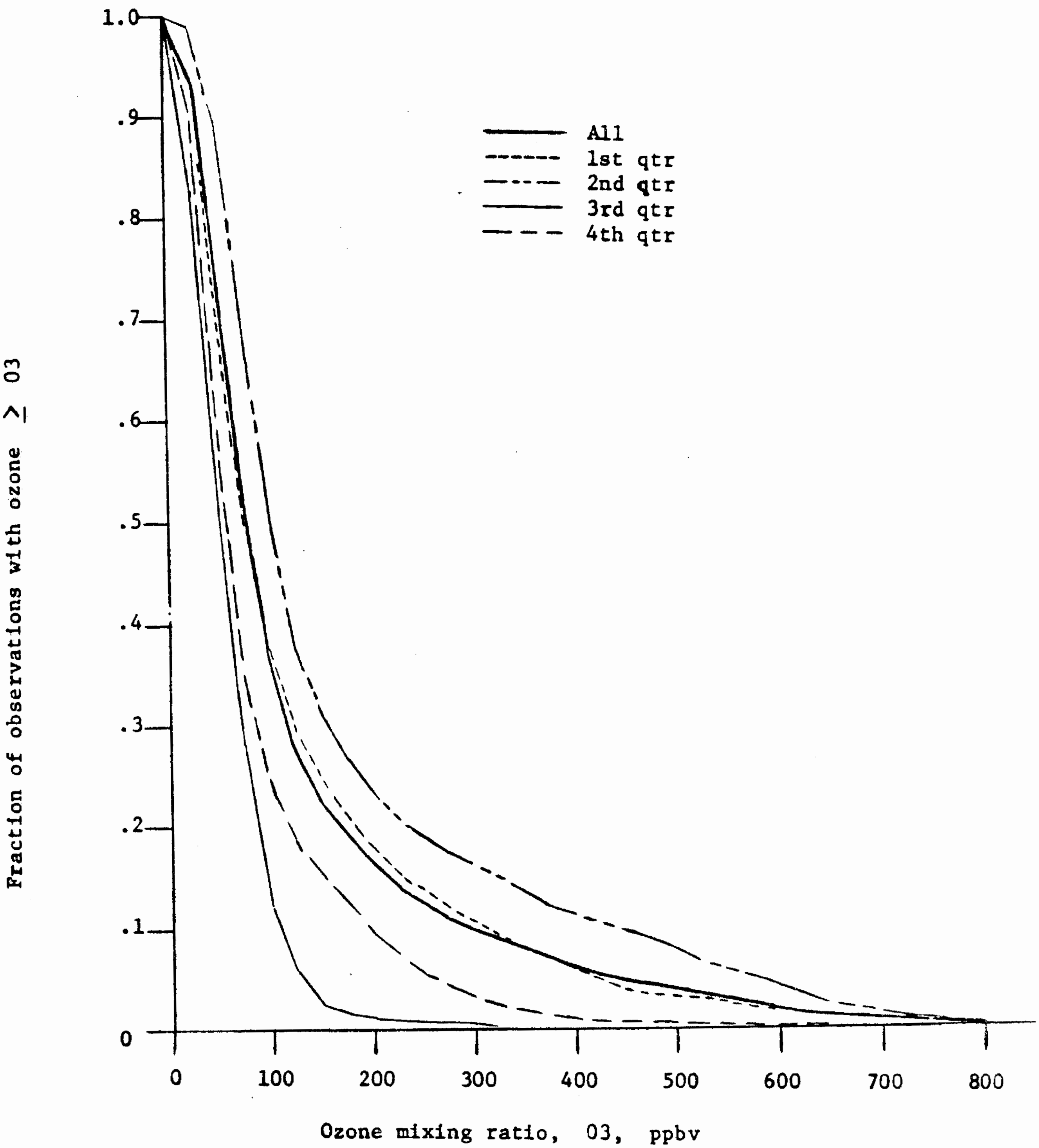

Figure 21.-Cumulative ambient ozone frequency distribution for N4711U

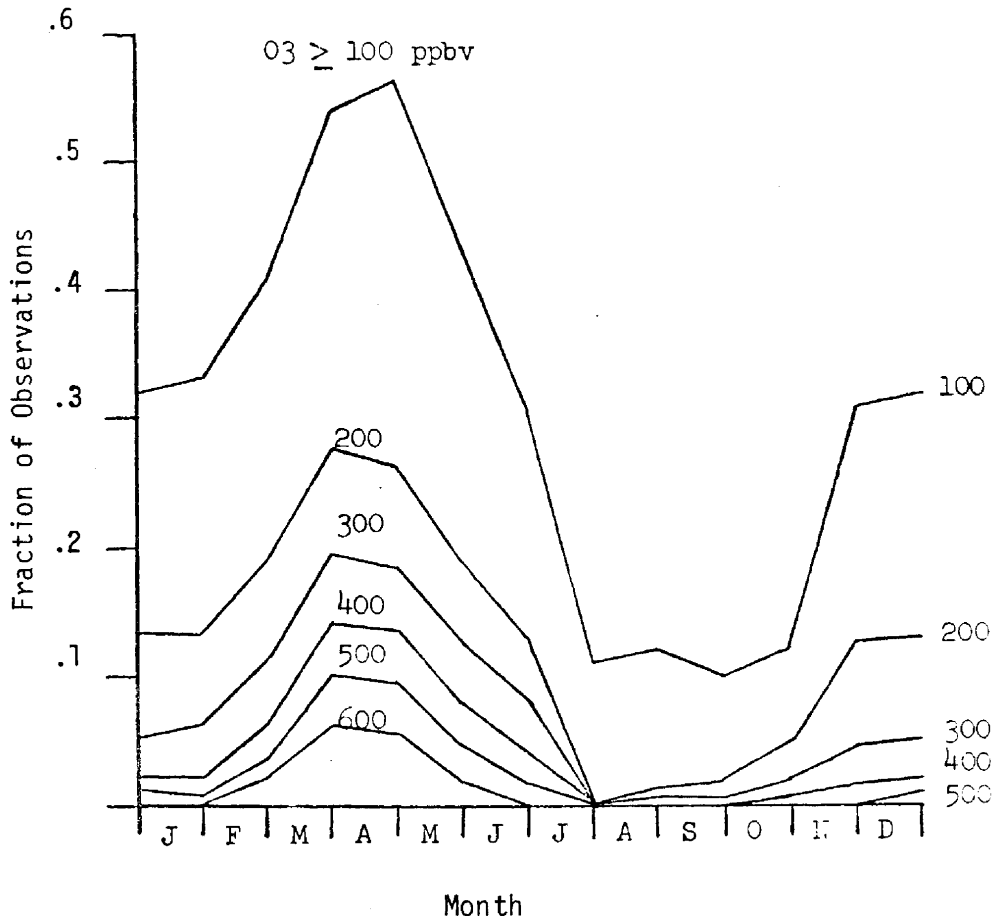

Figure 22. - Bimonthly Variation of Encounter Frequencies for N4711U

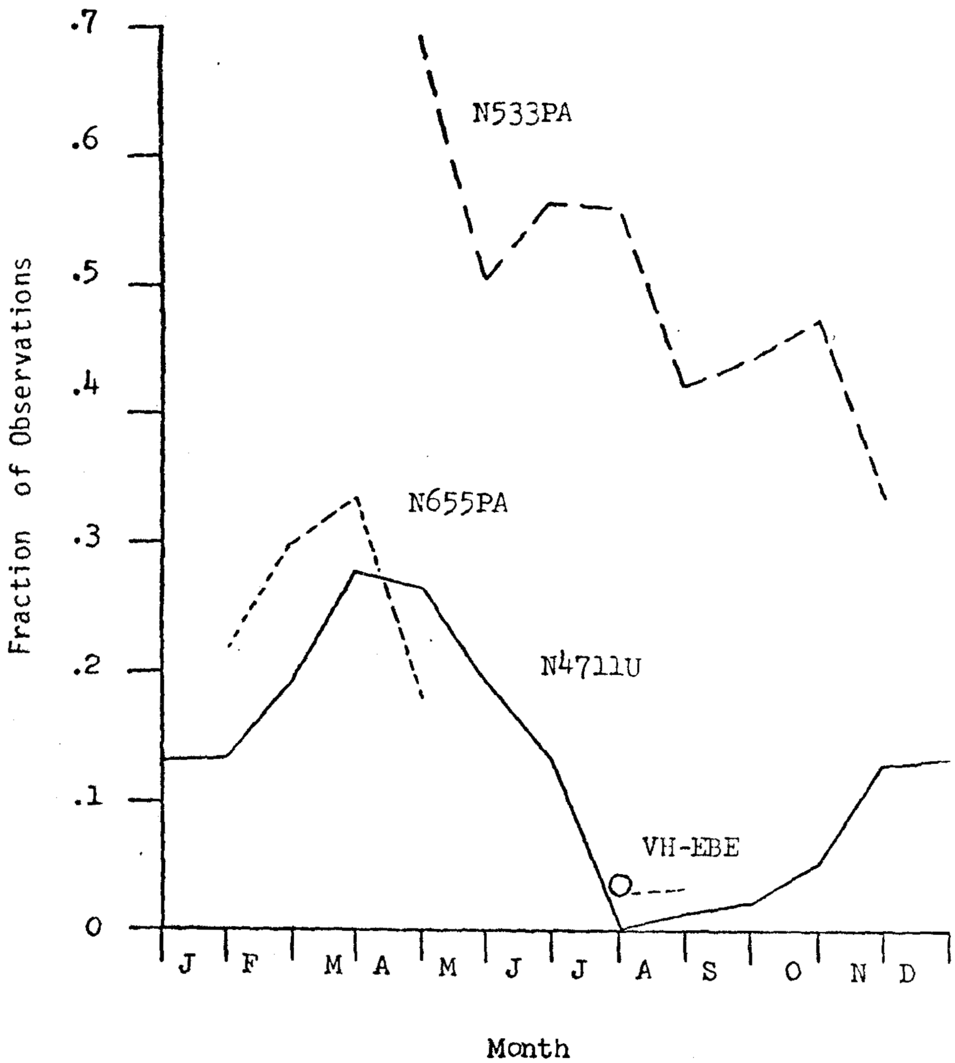

Figure 23. - Bimonthly Variation of Encounter Frequencies for $O_3 \geq 200$ ppbv

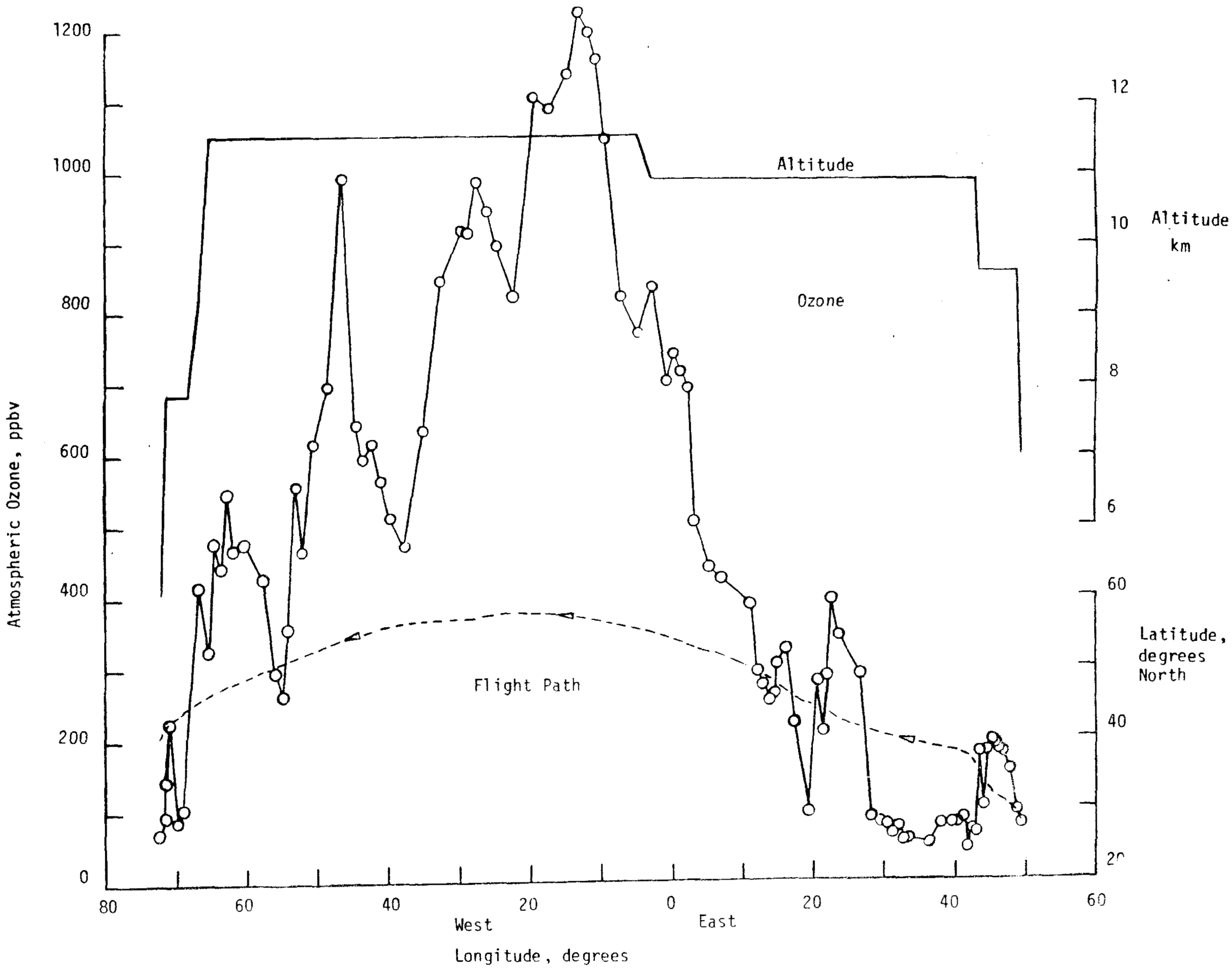

Figure 24. - Example of a high ozone concentration encounter

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15. Supplementary Notes

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16. Abstract

Simultaneous measurements of atmospheric (outside) ozone concentration and ozone levels in the cabin of the B747-100 and B747-SP airliners were made by NASA to evaluate the aircraft cabin ozone contamination problem. Instrumentation on these aircraft measured ozone from an outside probe and at one point in the cabin. Average ozone in the cabin of the B747-100 was 39 percent of the outside. Before corrective actions, ozone in the cabin of the B747-SP measured 82 percent of the outside. Procedures to reduce the ozone in this aircraft included changes in the cabin air circulation system, use of the high-temperature 15th stage compressor bleed, and charcoal filters in the inlet cabin air ducting, which as separate actions reduced the ozone to 58, 19, and 5 percent, respectively. The potential for the NASA instrumented B747 aircraft to encounter high levels of cabin ozone was derived from atmospheric ozone measurements on these aircraft. From March 1975 through December 1976 maximum ozone levels occurred in the spring for the Northern Hemisphere. Encounter frequencies for two B747-100's were comparable even though the route structures were different. The B747-SP encountered higher ozone than did the B747-100's. A more extensive data base will be obtained as the data acquisition continues.

17. Key Words (Suggested by Author(s)) Airline operations; Flying personnel; Aircraft hazards; Toxic hazards; Aircraft compartments; Cabin atmosphere	18. Distribution Statement Unclassified - unlimited STAR Category 03

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